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SOME EXPERIENCES IN ENGINEERING PRACTICE.

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THE following pages are the result of the wish expressed to me by Professor C. H. Peabody, that I should publish in the journal of this Institute the lecture which I delivered lately before the whole class of the fourth year students of the engineering section.

I have to a very large extent rewritten and revised my lecture, adding some subjects which limited time had caused me to exclude, and including other matters which I had relegated to my two subsequent special lectures delivered to the naval architect section of the class. In reading this lecture I wish students to regard it rather as suggestive than didactic, for I hold that there is no finality in engineering; though, on the other hand, there are unquestionably many facts which are established by experience beyond reasonable doubt. These latter I have intentionally accentuated. Such diagrams as I have introduced are purely diagrammatic, and therefore neglect all but the particular matter or principle intended to be described.

I begin with the subject of pattern-making, as a thorough knowledge of the pattern-maker's art is very needful to an engineer; it contributes much to the accuracy of foundry work, and in addition it will enable him to greatly reduce the cost of the pattern shop, as

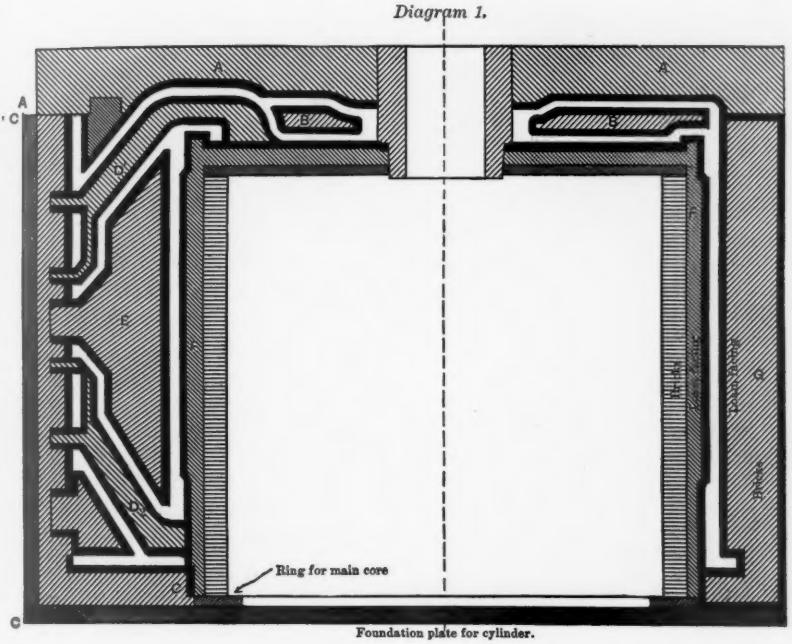
well as to keep within bounds the accumulation of patterns which is unavoidable in any large engine works.

I assume that my readers are conversant with the general ideas of molding from solid patterns and their core boxes; but as it is possible that they may not fully appreciate loam pattern work and loam molding, I intend to draw attention to the principles on which the latter are worked, for a clear comprehension of these opens the way to the benefits to which I have alluded above.

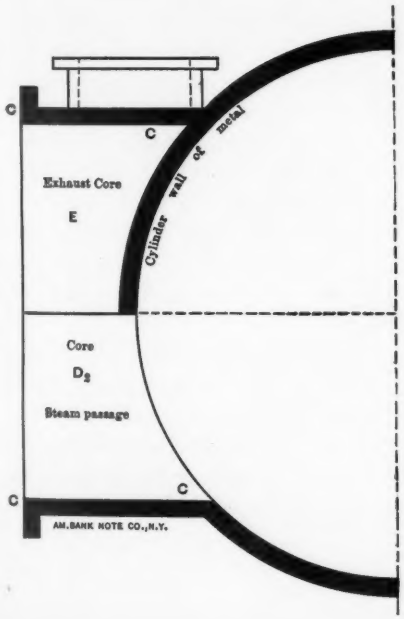
I have made a rough diagram showing the loam mold for a large cylinder, the spaces to be filled by the metal are left white. The pattern work required for this mold is as follows: 1. A wooden pattern representing the outside of the cylinder bottom with all that is cast upon it; upon this pattern is built, with loam, what is called the top cake (A). 2. A circular core box, which is generally struck up in loam by means of a strickle board and then adjusted by the aid of a little pattern work in wood, is made to produce the core (B) of the double bottom of the cylinder. This core is divided into segments by the radial ribs which bind the two plates of metal together, and so form the girder. 3. A large frame pattern representing the outside form of the box-shaped part (C) of the cylinder, wherein are placed the steam and exhaust passages. 4. Core boxes for the two steam passages D^1 D^2 and for the exhaust passage E; these are made as open frames, with sides only, cut to the form of the section of each passage as represented in the diagram. These cores are shaped by means of a strickle board guided on the edges of the sides of the core boxes. 5. The main body core (F) is built on the ground outside the mold upon a ring of metal as a base, by means of a large vertical post fitted with a radial arm, to which is attached a vertical strickle board which sweeps the loam to shape. 6. To form the main outer mold (G) the center post and strickle are employed as before, but previous to striking up the mold the frame pattern (2) of the box part (c) containing the steam passages is adjusted in position. It will be seen at a glance that the amount of actual wood pattern-making is very small compared with the importance and size of the casting to be produced.

Now, keeping in view the principles set forth in this system of pattern work, it will not require a great effort of the imagination of my readers to picture to themselves a considerable expansion of the adaptability of these principles, so that in many cases where only one or two reproductions are required it is possible instead of making

Diagram 1.



Foundation plate for cylinder.



elaborate and expensive wood patterns to make only a rough framework, which can be filled in with loam strickled up to shape and then dried, after which the dried loam model will itself serve as a pattern whereupon to build the mold. By the exercise of ingenuity much wood pattern work can be saved; but it requires a clear comprehension, and whoever undertakes it must have it all clearly depicted in his mind's eye before he makes a start, for even mechanical drawings cannot represent all the points of difficulty which may arise.

To return to the subject of molding, there is unquestionably some difficulty in making large castings whose thicknesses of metal shall be in accurate accordance with the drawing. This uncertainty of foundry work is so well recognized by engineers that it has become a custom to allow margins of thickness to guard against foundry irregularity. The molder on his part is very apt to rub down his cores or mold where, after drying, they do not thoroughly correspond. The result of these two additions sometimes appears in a very considerable excess of weight, which is very difficult to check. My attention was especially called to this subject by the pressure which was put upon us by the naval authorities when they reduced the weights available for the machinery of war vessels; hence I decided to make an effort to produce absolute accuracy in the foundry, so that the draughtsmen could reduce their thicknesses with security. To attain my object I had every core and mold gauged, and the whole mold taken to pieces a second time to examine the thickness of the balls of soft loam which were introduced as the gauges before finally putting together. By perseverance we trained the men so that we ended by producing a series of fourteen cylinders ranging from 74 to 90 inches in diameter, where the greatest error ranged only from + to $-\frac{1}{16}$ of an inch on a thickness of about $1\frac{1}{8}$ inch. We ascertained this positively by drilling the whole series of castings in all parts, and making gauges as records. The reduction of weight was so remarkable that I was sent for to the Admiralty to explain how the cylinder weights returned were so much below the usual standard.

Apart from the mere reduction of weights, thinner metal always tends to be stronger in proportion, which can be readily seen by comparing the fractures of two considerably different thicknesses.

I now pass on to the mixing and melting of the metal. Iron founding presents a valuable field for observation and adaptation of resources, and when skillfully managed has immense capabilities. It is

by no means a simple problem to produce large castings of the quality exactly suited to their special duties. In order to gain the necessary knowledge to conduct a foundry on best principles, an engineer should make himself acquainted practically with the methods of production of pig iron from the ore at the smelting works, and with the general principles of working the blast furnaces; he should also endeavor to accustom his eye to form a rough judgment of the physical properties of special pig irons by observation of the color, grain, and other peculiarities of fracture. A visit to a large smelting works will teach more than any amount of reading, and the engineer will there learn to appreciate better the classification by grade and number of the various pig irons produced. Analyses are, of course, of great value, but texture and grain also enter very seriously into the problem of success in practical founding; hence a practiced eye is a great assistance in suggesting mixtures and improvements in quality.

In addition to the importance of producing castings of the best quality great economy can be attained by skill in selection. It is frequently possible to substitute for an expensive brand of pig iron a mixture of two or more cheaper brands, which will produce an iron equally good at least, and in some cases better, by imparting other valuable properties which the single expensive brand would not have possessed. To attain success in selection you must not trust your judgment alone, but must always check it by casting regularly from your daily melting experimental bars, whose results should be kept in a book, compared and registered. There is no more useful way of utilizing a slack time in your foundry than by making a number of purely experimental mixtures. By steadily working on these lines at Maudsley's we succeeded finally in producing with regularity and certainty, and at moderate cost, a quality of cast iron which was from 40 to 50 per cent. stronger than the accepted standard, and yet was fluid enough to use in large cylinders and other intricate castings. The basis of this mixture was a large proportion of hand-selected engine casting scrap, which probably had been melted at least four times; to this basis we added, according to the purpose of the casting, two, or sometimes three, different brands of fresh pig iron in proportions determined by previous experiments.

The great value of a regular system of experimental bars is accentuated by the fact that it is a matter of common experience that sometimes, in a comparatively short period of time, brands of pig iron

produced at the same smelting works will vary materially from an engine founder's standpoint. I do not think the explanation is far to seek when one remembers the immense variety in the mineral products of nature, and the immense difference in properties which occurs sometimes between two contiguous seams of coal in the same colliery.

My readers must please remember that in all I have said above I am not advocating an elaborate and costly system of experiments, but only the simple method of casting regularly 1 inch square bars of a standard length, which are to be broken between standard supports, the results being registered. I reserve complete experiments only for those cases where the mixtures are of great promise and are likely to repay the trouble and outlay.

I pass on now to the melting process. I personally never have had the slightest desire to return to the use of the reverberatory air furnace for melting iron, not even for the most critical work. I have found the cupola to give splendid results when well managed. In what follows I assume that my readers are generally acquainted with the cupola furnace, but I believe that I shall give them a closer insight into the principles of its management if I carry them through my own personal experience.

When I started as a member of Maudsley's firm I found that it required about eight hours or more to melt 42 tons. To do this there were in blast four cupolas, whose respective capacities were about 15, 12, 10, and 6 tons. It was then the usual custom to accumulate the metal on the hearth of the furnace, which of course involved raising the tuyeres according as the level of the molten metal rose in the cupola. The blast fans were driven, as is very commonly done, from one of the lines of shafting in the works, and hence were subjected to all the small variations of speed which occur in such cases. The consumption of coke per ton of iron melted was roughly $2\frac{1}{2}$ hundredweight, certainly not less. When the furnaces were tapped the bottom metal was rather dull after lying so long, but the average temperature was very fairly good and the resulting castings were sound. Still, I did not feel contented; there seemed to me possibilities of great improvement, and in this view my dear friend, the late Mr. John Timme, the works manager, cordially agreed. I accordingly started to entirely reorganize the whole arrangements for melting upon the following lines, which were more or less suggested to me by my observations of blast furnaces.

1. In order to have a much higher pressure of blast I ordered a very large diameter fan, which at full speed would give a pressure equal to a head of about 12 inches of water. 2. This fan was to be driven by a separate engine reserved for this duty alone, so as to insure perfect steadiness of blast. 3. I had an iron blast main 3 feet in diameter fitted, upon which were placed the standpipes for the tuyeres; each standpipe was provided with a shut-off valve, and the tuyere pipes were made to slip into place quickly by means of a bayonet joint, so as to reduce the time required for shifting the tuyeres. 4. In view of the increased pressure of blast (from formerly 3 to $3\frac{1}{2}$ inches of water to 11 inches) we raised the charging door about $2\frac{1}{2}$ feet, so as to have more material to absorb the escaping heat.

The result proved most satisfactory, and with an air pressure of 11 to 12 inches of water the metal was white when it came from the furnace, the coke consumption greatly reduced, and the time of melting, also. After about a fortnight my big fan unfortunately exploded, and as it was absolutely necessary to make some more very heavy castings immediately, I purchased the largest fan which I could find in the market, but at the same time increased the volume of the blast. We started again with 9 to 10 inches of pressure, and continued to do so well that I decided to be content with the new fan. In a little time my old friend Mr. Hugh Gray, the foundry foreman (a Scotchman), suggested that he should tap the metal out of the furnaces, one ton at a time, into the ladles, instead of having it accumulate in the furnace, whereby he intended to save the time and the labor of raising the tuyeres, which involved checking the furnace for eight minutes each shift. He had the ladles lined extra thick to prevent the heat soaking through, and at each tapping threw on the surface of the metal a lot of fine charcoal and coal dust, which made a solid black cake on the top. There was a very decided gain in the time required for melting after this was commenced, and when we had reduced the diameter of the furnace for about 4 feet above the zone of fusion at the tuyere (which made the cupola pretty much like a blast furnace bottom), we had arrived at the climax.. This proved to be that we could now, with only two furnaces in blast, melt 16 tons of metal per hour on a consumption of 1 hundredweight of coke per ton of iron; but in addition the metal in the ladles was so hot that we had to let it stand a long time before we dared to pour it. This proved to be a very great benefit, for I have watched the ladles for long periods

after the crust was removed, and observed that the metal was in constant motion and always engaged in separating from itself impurities which it threw up to the surface. I am convinced that the great homogeneity of our castings partly sprang from this cause; they were very dense and bright, as well as homogeneous, and were absolutely free from the peculiar cloudiness which in our earlier metal suggested to me the presence of graphite in suspension. Dr. Percy found graphite in several Scotch brands of pig iron where the pressure of blast was too low for the duty, and carbon therefore remained in excess in the furnace.

The great reduction of coke consumed per ton was of course mainly due to the very large mass (nearly 9 feet) of material now carried above the tuyere, which absorbed much of the heat which was formerly wasted.

I have dwelt very long upon this subject, not only because of its importance, but also because I found when I tried to collect information from others at the time of our contemplated reorganization that very few persons knew what they really were doing in their foundry; a great deal too much was taken for granted as long as the castings were sound, for no foundry foreman can devote himself to experimenting without neglecting his other duties; besides which my experience has shown me that it is almost as easy to fall unwittingly below the standard strength with an apparently good mixture of iron, as it is to rise above it.

My next subject is the shrinkage of castings. Cast iron shrinks $\frac{1}{16}$ of an inch to every linear foot when cast in bars, but my observation of large and intricate castings has proved to me that this rule is only a vague indication of what is likely to occur. I have known cases where a cylinder of 85 inches in diameter did not shrink at all in diameter, and another instance where it became oval, actually expanding slightly in one direction without shrinking in the other. These and other circumstances led to my making a few experiments to see if I could find out any indication of a rule. I cast circular solid plates and rings of same diameter and thickness, but never succeeded in establishing any rule; the results were utterly anomalous and illogical. I had so much else to do that I had to leave this subject for other work more pressing, but it is a subject which would, I believe, well repay the Institute of Technology to investigate patiently.

Strains from shrinkage are very long lived. I have known cases

where pistons, which were apparently perfectly sound, have broken many months later at sea from what were undoubtedly shrinkage strains, which had gradually developed a fracture. Such examples as these emphasize more strongly than any words of mine the value of selecting iron suitable for special duties.

I will say one word of warning as to designing large cylinders. It should always be remembered that where ribs spring from the face or body of a cylinder there is a decided risk of sponginess or a "draw" occurring in the wall of metal. If the ribs are made decidedly thinner than the metal whence they spring this risk will be very greatly reduced. The hydraulic test generally reveals the evil, but it is often very difficult to discover whereabouts it starts, and generally more difficult still to remedy it.

The alloys of copper are too numerous for me to speak of, hence I restrict myself to a few cautions.

Be very careful of your mixtures and of the purity of their components; also be as careful of the way you melt and mix them.

Believe in nothing without checking it by experiment, as a small loss by evaporation of one of the more volatile metals may entirely vitiate your result.

I now pass on at once to the all-important subject of steel castings. I will preface my remarks by a simple caution. If you humor steel and adapt yourself to its demands, it will prove an excellent friend; but if you proudly try to force it, you will find it an almost irresistible opponent. This lesson remains firmly impressed upon me.

At the very outset steel presents great difficulties. The shrinkage is $\frac{3}{16}$ of an inch per linear foot; the temperature of molten steel is so high and the metal so searching that the molds and cores have to be made of a refractory material which is as hard and rigid as sandstone. The consequence of this is that any form which grips the mold or core, and has no means of easement, must set up incalculable strains in the angles of the casting during cooling; sometimes these strains will produce gaping cracks, but more often there occurs a multitude of fine flaws scarcely discernible by the unaided eye.

My firm was either the first, or one of the very first, who attempted to employ cast steel on a grand scale throughout marine engines. We employed Messrs. Jessop, who had peculiar facilities for turning out large "pot steel" castings, with which we first began; then we followed them into open hearth steel, which gave greater range in weight

of casting. When we started I determined to go very cautiously to work, so as to avoid risks and gain every one's confidence in our steel work; therefore, after preparing our designs for cylinder columns and foundation frames, I invited the most practical steel founder of my acquaintance, Mr. Frank Hall, of Jessops, to come and criticise them from his own point of view. The outcome of our combined efforts was that our very first order for twenty-four cylinder columns and twelve large foundation frames was completed without one single failure or flaw. Some years after I had occasion to go through our steel record and found that out of some thousands we had had to reject less than 2 per cent. We adhered firmly after our first conference to the H section, to the exclusion of the box section, and later experience has more than ever confirmed me in the opinion that it is practically impossible to produce a large steel casting of the box form which shall be absolutely free from "strains" in the corners. I have met with a great deal of trustworthy private evidence confirming this.

After we had fairly started in steel and had begun to take full advantage of its strength, I found some cylinder columns delivered which showed slight symptoms of straining in the extreme angle joining the web to the plates of the H. I therefore had Mr. Hall come to see them; in course of conversation he suggested strong brackets, but he reserved judgment until he returned to Sheffield to examine more castings; then he wrote, asking us to try very thin brackets, only $\frac{1}{4}$ of an inch thick, saying that, as these brackets would set before either the web or plates, they would form a firm tie to both and distribute the shrinkage strain over a large area. This proved to be absolutely correct.

Steel forging is too large a subject for me to deal with properly in any general way, but I will include a few instructive examples from practice which will be of value. I wish to premise that when I speak of steel forgings in our own works it is to be understood that each one of them, like all our steel castings, had been properly inspected before leaving the steel-maker's hands, and that test pieces had been cut from each article which had been tested in a powerful machine and then stamped in regular order, noting the tensile strength and elongation.

To proceed; a large forked-end connecting rod, having a T at the other end, is more or less difficult to produce in steel so that it shall be absolutely free from defect. An imprisoned gas bubble will extend

in the forging process, causing an internal flaw, besides which there are plenty of other possibilities. Usually these rods are forged from an ingot sufficiently large to produce the T end, and as the piping of an ingot generally extends to two fifths of its length, the original ingot is very large and the waste cut off considerable. The ingot is forged down to shape and is laid down with a solid mass at the fork end. In the days of wrought iron forgings I had observed, first, that when we slotted out the fork of one of these rods (diagram 2, page 195, Figures 1 and 2) that the sides of the fork had a tendency to spring inward, which was exaggerated when we parted in two the solid heads of connecting rods made as in diagram 3. This indicated the existence of strains set up by the cooling of such a mass; besides this I had noted that the lump cut out of these masses was decidedly more crystalline at the heart, which one would expect. These two circumstances gave me a prejudice against solid forks, hence I determined to try and avoid

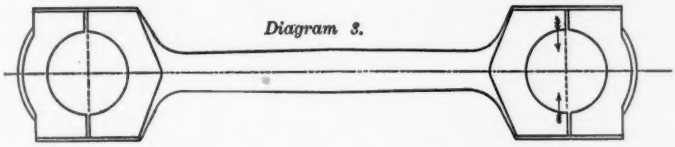


Diagram 3.

them in steel. I mentioned my views to Mr. Frank Hall, and found that he also wished to move in the matter; but he was actually going to cast some connecting rods to shape in a special quality of steel. I thought this was going too far, and that he was introducing other risks, so I asked him to cast for us ingots having at the bottom end a roughly molded fork, which, from its being subjected to the great pressure due to the whole head of molten metal in the mold, could not fail to be sound and free from bubbles. The remainder of the rod was to be forged as usual out of the mass of the ingot above. These rods proved thoroughly successful, but as this was a departure from general practice I took the extra precaution of making a complete set of check tests from pieces which were trepanned from both sides of the fork, from the T end, and from both ends and middle of the shank of the rod. These latter were facilitated by our having purposely designed the rod to be bored throughout its length for strength and lightness. When this $2\frac{1}{2}$-inch hole was finished we examined the interior by means of a mirror at one end and a light placed at the other.

All the tests came out correctly, corresponding very closely with the original results at Jessop's works. After we had established our set of trepanning tools we often had recourse to check tests, which are very reassuring.

It may be of some interest to my readers if I give an account of the discovery of a defective rod. The connecting rod in question resembled closely that shown in diagram No. 2; it had been carefully examined by the marker-off in the machine shop, and had nothing about it to excite suspicion. It had been machined all over, except the flat across the fork end where the fork springs from the shank which was then in progress. By chance I was detained near it, and while discussing some matter I had my eye on the slotting tool and observed that it tripped very slightly in passing a particular line along the fork. Mr. Timme and I went to see what it was, but found nothing more than a slight trace of a line about half an inch long and finer than a gossamer thread. However, as it was the first rod of a set, we thought we would put a wedge in the fork just to reassure ourselves. The half fork broke off at the third blow, revealing a large flaw like Figure 3 on diagram No. 2. We tried two more rods with the same result, and then returned all the set to the makers, a most respected firm who were much distressed about it. Later experience has led me to believe that they were all cases of imprisoned gas due to the ingots not being large enough for the forging, but at that early time it was a mystery to all concerned.

I now come to boilers and boiler work, and as the many types of marine boilers include all the difficulties and troubles of other boilers in addition to some special troubles of their own, I shall take marine boiler work as my subject.

In these days when steel plates and machine tools have reduced boiler-making to a comparatively simple system, I think there is some danger for those who have not grown up with it to miss some of the important principles involved. I have therefore determined to follow in this case, as before, the method of carrying my readers through my own practical experience and reasoning. This will not be wasted time, because whenever serious repairs are needed you must, perforce, return to hand work, and that frequently under difficulty and disadvantage.

In the old days of low pressure and "box boilers" (where the sides and all parts of the outer shell depended entirely on stays), plates seldom exceeded $\frac{7}{16}$ of an inch for the sides, and $\frac{1}{2}$ inch for the bottom

Diagram 2.

FORKED CONNECTING ROD.

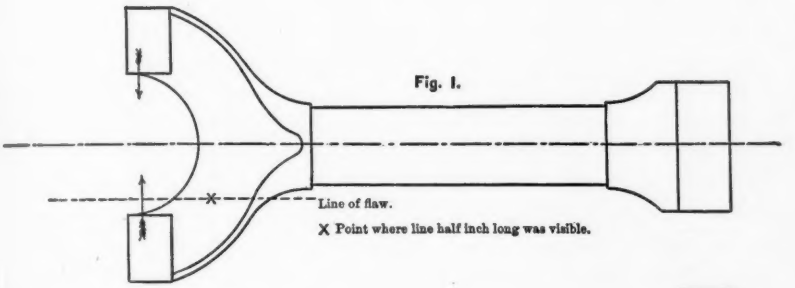


Fig. 1.

Line of flaw.

X Point where line half inch long was visible.

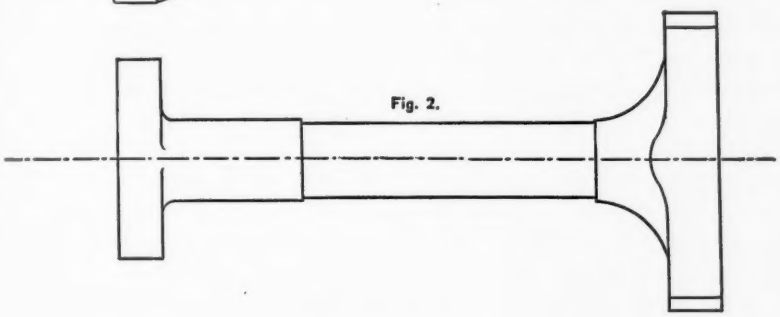


Fig. 2.

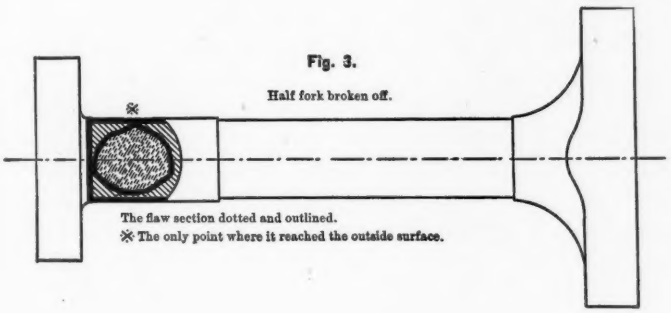


Fig. 3.

Half fork broken off.

The flaw section dotted and outlined.

※ The only point where it reached the outside surface.

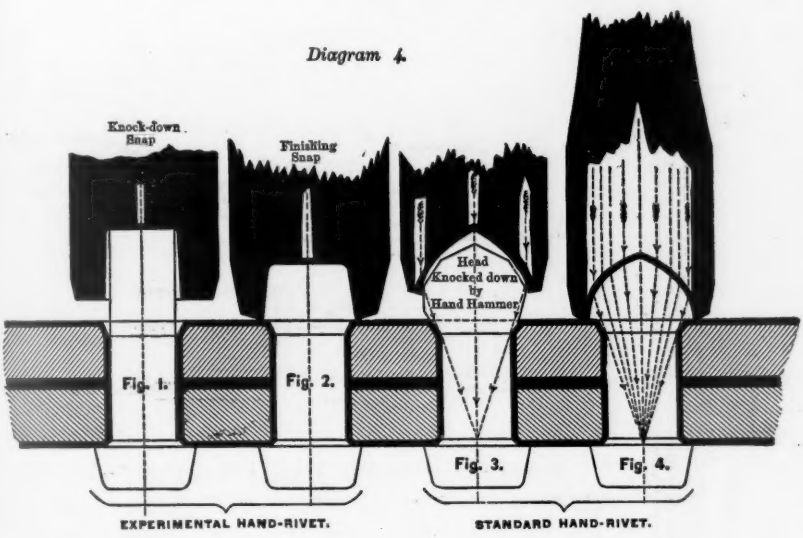
plates; rivets were generally $\frac{3}{4}$ inch diameter, and at most $\frac{7}{8}$ inch; hence it took but little skill to make rivets fill the holes in such thin plates, and a good head could be formed by a snap tool whose section was a segment of a circle. The boiler drawing in those days was more of a suggestive diagram showing the spacing of the stays than a full working drawing, for the foreman of the boiler shop had to deal with a forest of stays crossing each other, which he had to keep apart from actual contact by humoring them a little according to discretion. After 35 pounds pressure there came a sudden break; cylindrical boilers with 60 pounds pressure of steam and the compound engine came out together. Shell plates grew much thicker as pressures increased, and rivets also had to be made larger and longer.

One day I received from a Liverpool engineer a bag full of rivets which had been cut out of one of our boilers where the thick tube plate joined the furnace crown. They all had been leaking, and clearly had not filled the holes except for a short depth under the snap head, though the boiler had been perfectly tight under 125 pounds hydraulic pressure. I went to Liverpool and examined all the holes which were good; then I realized that all hand work required complete reorganization if we were to have tight work with thick plates and high pressures.

I started on the principle that the rivets must be first made to fill the holes absolutely, and that the head was an after consideration. To insure this I made the riveters cool the point of each rivet nearly black before putting it in; then I let them give a few blows with their hand hammers to steady the rivet, after which they had to apply snap No. 1 (diagram 4, Figure 1), using only sledge hammers. When this was solid the finishing snap tool was applied (diagram 4, Figure 2) till the rivet head was finished. As will be seen by the diagram the snap head was small and had little cover, only just closing over the partial countersink in the plate. When the set of boilers were completed I had about 5 per cent. of the rivets' heads cut off all over them, and found that it required from seven to eleven blows of a sledge hammer to punch out the parallel body of the rivet. The riveting of these boilers was ugly to look at, but the boilers remained remarkably tight after several years' work. It was clear that I had grasped the right principle, but the work was so severe and tiresome to the men that some modification was necessary to avoid the risk of men shirking in the absence of the foreman. As the cover of the rivet heads above

mentioned had proved to be rather too small on examination of those cut out, I increased the diameter of the head. Then I allowed the men to cool the rivet point very slightly only, and to knock it down another stage with the hand hammers (see diagram 4, Figure 3), using only one snap tool to make the rivet fill the hole and finish off the snap head. This new snap tool I had myself schemed on the principle indicated by the dotted lines on Figure 4, diagram 4, so as to direct all the force of the blows inside the rivet hole to a point just under the pan head, the snap head not beginning to be formed until

Diagram 4.



the hole would refuse entry to any more material. The peculiar point of the snap acted as an excellent telltale, for if the rivet was too short or did not fill the hole there would be no point to the snap head.

After this all went well until the great increase in thickness of shell plates demanded again larger rivet work. The men could do 1 inch work pretty well, but $1\frac{1}{8}$-inch riveting was practically beyond their power; hence as soon as Mr. Tweddell brought out his hydraulic riveter we ordered one made. This difficulty was scarcely over when we began to find that with the increasing thickness and size required iron boiler plates were rapidly deteriorating and becoming more and

more laminated. This was threatening to bring steam pressures again to a standstill, when Dr. Siemens started his first open-hearth Siemens-Martin mild steel furnace at Landore. The British Admiralty gave him a trial order for the ship plates of the two fast cruisers, Iris and Mercury, for which vessels we held the contracts for the engines. After seeing the quality of the mild steel, we offered to construct the boilers of this material at our own risk. These were the first mild steel marine boilers.

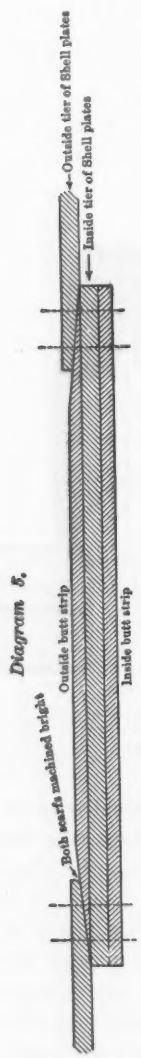
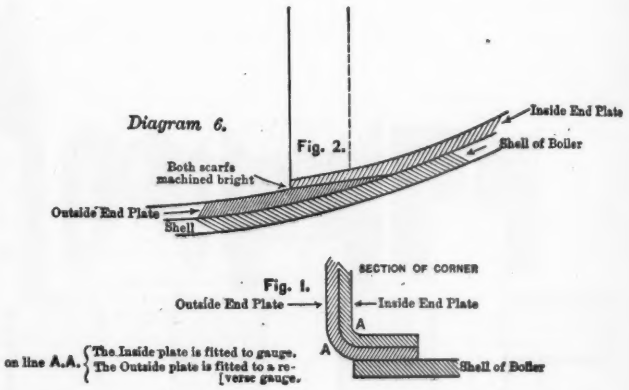

Outside tier of Shell plates
Inside tier of Shell plates
Outside butt strip
Inside butt strip
Both scarfs machined bright

Diagram 5.



It very soon became evident that there would be almost no limit to the size of steel plates. I therefore decided to set to work at once to sweep away all the remaining hand work and to replace it by special machinery, as being the only certain method of insuring perfect boiler work for high pressures. I have given in diagram No. 5 our method of making butt joints by machining together the scarfs of the outer butt strip and the shell plates where the butt strip was tucked in. Diagram No. 6, Figure 1, shows how the front plates were brought together with fitted corners and scarfed together in the machine as seen in Figure 2, thereby preserving the true circular form of the built-up front plate without any break or crevice.

Where joints are not so fitted there are always points where the

tightness depends on the calking or on a wedge piece driven in to fill the gap. I do not consider such work admissible with the modern very high pressures, as even if the joints are tight at first there is almost a certainty of their weeping after the boilers have been at work some while.

In the days of iron plates it was usual to thin down the corners of plates in the fire, and sometimes even to light a fire against a joint of the boiler so as to close it in place. This custom remained after the introduction of steel, but very soon it was discovered to be most pernicious, as the local heating of steel plates sets up all manner of strains when cooling, and generally cracks the plate at that part.

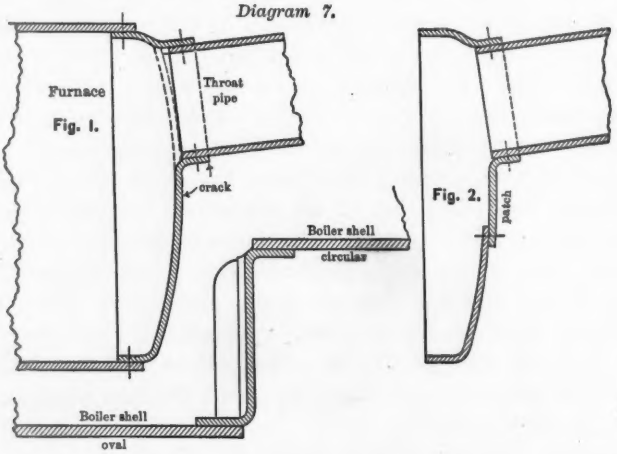
I will relate our earliest experience in order to emphasize this point. A shell plate had been heated and thinned at the corner by hammering; about an hour later it cracked with a loud report, the crack extending inward about 9 inches. The maker came to see it, and was somewhat puzzled, as he declared the plate was perfect by test. He consented to my proposal to continue the crack by hammering in steel wedges, but added that he did not believe the crack would go further, which proved correct. The frequent recurrence of these cracks in several works led to the publication of the danger of local heating of steel plates. Of course where plates have to be heated for flanging, they have to be carefully annealed before laying them down. All steel stays should be worked out of the solid, for welds are not to be trusted in such vital parts; even the best welds are very liable to be crystalline.

When stay tubes are used in a boiler the threads of the two ends must absolutely correspond in pitch; in other words, they must be continuous, and when properly made should screw into both plates with quite a moderate strain. Whenever stay tubes require much forcing it is almost invariably due to the threads not being continuous, which is very mischievous, as it tends to buckle or spring the tube plates. It requires some care to make a good set of continuous threads, but with accurate gauges the tools can soon be established.

Boiler repairing and patching generally has to be done on board ship, and very often under great difficulty. It requires good judgment and all the experience and ingenuity you can command. When a patch has to be put on a furnace the patch should be applied on the water side of the plate if possible, as on the other side it never stands well for a long while; the rivets in all furnace and flame box patches should

be countersunk and well knocked down to keep them from the rush of the flames. I will mention only one example of a patch, a pretty bad one, however, where by a lucky idea I got out of the difficulty of patching inside the furnace throat. Diagram 7, Figure 1, shows the position of the crack which occurred in the dome-shaped plate, forming the end and throat of the furnace of a Holt boiler. The plate had been made from a large circular flat plate, and was therefore much punished in working into form. The crack was in an inaccessible position; you had to go head downwards, and then could only reach

Diagram 7.



the crack with one hand. I bethought me that one hand could support a light box, and that if we cut out the crack we could make a plaster of Paris mold of the whole surface by pouring the plaster through the hole into the box. This succeeded admirably, so that we cast from the plaster of Paris model a reverse whereon we could absolutely finish the patch before offering it in place. This patch was in perfect condition five years later when I last inquired after it. It is represented in diagram 7, Figure 2.

The subject of repairs leads me to mention a very important matter, which, however, mainly affects marine boilers, though the principle involved is of general application. I refer to the accumulation of oil or grease upon furnace plates.

The use of surface condensers necessarily collects somewhere in the engines or boilers every drop of oil used on the internal parts of an engine. When pressures were moderate and salt water was still admissible into the boilers, it was a common practice to dose the surface condensers with caustic potash so as to dislodge the collected grease, and then to work as a common jet condenser for a few minutes so as to pump all the grease overboard through the discharge valve. With closer staying this practice was stopped, and there occurred from time to time serious bulgings of furnaces, also some collapses of crown plates attended by loss of life. Inquiry showed there had not been shortness of water, and I believe Mr. William Parker, then the Chief Inspector for Lloyd's, was the first who suspected grease as being the true cause, in which, after a long series of experiments on greased plates and some unfortunate confirmation on a large scale at sea, Mr. Parker proved to be absolutely correct.

I had the privilege of knowing Mr. Parker, and he gave me an interesting specimen of water and oil taken from a large Liverpool liner's boilers. The grease remained always collected in a large spheroidal mass; some days it would be floating on the water at the top of the bottle, and on other days it would lie on the bottom. Probably this arose from change in atmospheric pressure, but it was very suggestive of what occurred in boilers under steam. Now all engines are being fitted with filters to collect the grease from the feed water before it enters the boilers.

Before finally leaving the subject of boilers I wish to draw attention to an oversight which is not uncommon in arranging the staying of the flat crowns of flame boxes and furnaces, which destroys the equilibrium of the circular shell above them. Sometimes with very high pressures it is very desirable to relieve the thin vertical plates of these flame boxes and furnaces from the great pressure transmitted to them by the bridge bars which support the flat crowns; this can be done by carrying hanging stays upwards from the middle of the bridge stay, or occasionally the bridge stays are omitted and separate vertical stays are distributed over the flat surfaces. In either case, to attach these stays to the shell of the boiler must destroy the equilibrium of the circular form, unless you compensate the half shell to which they are attached by working inside it a T iron or double angle iron, which shall carry this extra strain like a bridge springing from the lower half diameter. No doubt plates are very long suffering and that there are

plenty of boiler shells at work in this unbalanced condition; but that does not make it right, nor would those boilers now pass the rules of Lloyd's nor of the British Board of Trade.

I now leave boilers, and will deal with a question which materially affects the successful working of machines in a manufactory. I refer to the steel cutting tools themselves. The best angles for tools which have to cut the various metals have long ago been established, and were first published in admirable detail by the late Mr. Holtzappfell in his original and very important work on mechanical manipulation; but he, like those who have followed him, seems to have overlooked one point in theory of construction of cutting tools which happened to force itself very notably upon me in practice. When we received our first large steel castings from the makers, we supposed that they would require a slower speed than wrought iron, and allowed twice the time for machining them; but we had only started a few days when the foreman came to me in despair, saying that it was useless to attempt such a speed. I accordingly went myself to see what could be done. I found that it required six times longer than wrought iron. I examined the men and their tools, and found that the strain on the machines was really very great. I tried another tool steel, but in vain. I noticed, however, that the extreme cutting edge was blunted by being almost fused by the heat of abrasion and not so much from being ground away, yet it was impossible to get water to it; whence it suddenly occurred to me that if the mass at the front of the tool close to the cutting edge were very great the heat would be rapidly conducted away by the mass of metal. I had a 2-inch square section steel brought, and filed the square end back just sufficient to clear the work, and on the front side I hollowed out only a sufficient curve to allow the cuttings to curl up, making the cutting angle as for iron. When the machine was started all went well nearly at same speed as for iron, proving that I had struck on the right theory.

I will now make a few observations on the question of the value of steam jackets, for which I have been until the last few years a consistent advocate. My doubts began only when we began to increase so much the speed of piston and the number of revolutions per minute, which appear to me the most important factors of all in estimating the value of steam jackets. Steam jacketing began with the celebrated Cornish engines, which had a long stroke and made at most about $4\frac{1}{2}$ strokes per minute; this is perhaps the best possible case for

the use of a steam jacket, the more so as there is quite an appreciable time between the closing of the equilibrium valve and the opening of the exhaust, during which time the heat can flow pretty freely through the metal wall of the cylinder and help effectually to heat up the internal surface. Now, when you contrast the modern fast-running engine with the Cornish engine you cannot fail to see that the case is exactly reversed, and that the fluctuations in temperature inside the cylinder occur, as it were, in a moment of time and can only affect a very slight depth into the metal wall, while the heat from the jacket cannot quickly reach the internal surface of the cylinder as it has to travel through the entire thickness of the wall; in other words, it arrives too late.

Since I delivered my second lecture, in which I mentioned these views, I have received from the Institution of Civil Engineers in London Mr. Bryan Donkin's valuable paper on condensation of steam in cylinders, giving a full account of his very careful experiments, which confirms the accuracy of the above reasoning. I think, however, that there remains an argument in favor of steam jackets; namely, that they act as a perfect casing to the cylinders as against external radiation; and as it is customary in all marine engines to fit separate working barrels, it costs very little to make the space between the barrel and the outer shell available as a steam casing or steam jacket, if that name is preferred.

In conclusion I desire to repeat and to emphasize the advice I gave to the whole class when I delivered my lecture orally: "Go into every department of some large engine works and work with your own hands as a common workman, and with your brains as a graduate of this institution!" There is no other royal road to become a thorough engineer.

That which you will learn by practical and manual work in the shops is of a quality which cannot be produced by any scientific institution. The learning of the manual use of tools in your workshop here is excellent, but that is not enough. It is only the prelude to practical engineering where in a large works you will daily find yourself face to face with the difficulties of handling large pieces of work. This is the class of experience which opens your mind and where your store of scientific knowledge accumulated in this institution will begin to have full play and will give you much quicker insight than others into the underlying principles of things. I speak from positive

knowledge and experience, besides which I could quote lists of distinguished engineers who would bear the same testimony.

In addition to all I have written above I can quote the lower motive of self-interest as a forcible argument, for there are numberless positions from which the lack of a regular workshop training would tend to exclude you. No large ship-owner, nor other man in a responsible commercial position, can afford to run risks in the choice of a man who is to have a great charge. He will wisely prefer the so-called practical man, even if he is no genius, to any man lacking real practical experience, no matter how able or scientific he may be.

You must remember that the workshop-trained, unscientific, but practical man cannot avoid absorbing a good deal of what I may be permitted to designate as "practical theory and science" by simply observing what surrounds him when he is at work in shops or the engine room; hence this man is not really devoid of science, and although his theoretical knowledge may be narrow, yet he will not be averse to move on steadily and cautiously. Such a man has no mean value, commercially speaking. It needs no further words of mine to demonstrate the beauty and the value of combining science with practical experience.

I am perfectly aware that what I am demanding from you requires some sacrifice on your part, and may even involve a strain on your parents' resources; but if they can afford to wait, their patience and yours will reap a large and full reward.

AN APPARATUS FOR MEASURING DIFFERENCE OF PHASE BETWEEN ALTERNATING CURRENTS.

By LOUIS DERR, M.A., S.B.

Most of the methods hitherto employed for the measurement of difference of phase between alternating currents (*vide La Lumière Electrique*, March 10 and 17, 1894) assume that the currents measured are truly sinusoidal in character, or demand exceptional conditions of steadiness. The method here described is applicable to the measurement of periodic currents of any form whatever, and can be used under ordinary conditions.

The apparatus is a modification of that employed by Dr. J. Puluj for a similar purpose, and described at length in the *Elektrotechnische Zeitschrift* for December 1, 1893. Dr. Puluj's apparatus consists in brief of a pair of electromagnets, each carrying a flat steel spring at the free end of its core, a small mirror being mounted on the spring. A beam of light is reflected from one mirror upon the other, and thence to a screen. If alternating currents are sent through the magnet coils, the springs will be set vibrating, and the spot of light on the screen will be lengthened into a line if the springs are parallel; and if the springs be turned so that the vibrations are perpendicular to each other, the line becomes an ellipse whose dimensions afford a measure of the difference of phase between the currents in the coils.

It is evident that to maintain an ellipse sufficiently stable to permit measurements of precision requires great steadiness in the currents, a condition not always obtainable. The springs give best results when their period of free vibration is that of the current or its octave, and slight changes of the current period will throw them out of tune, instantly affecting the amplitude of vibration, as the inertia of the moving parts is very small. Belt slip at the generator, irregular load or changes of steam pressure, make precise measurements very difficult.

To obtain results without the steadiness demanded by the above method, the following modification was devised by the writer and suc-

cessfully used by Messrs. L. R. Nash and J. C. Nowell, of the class of 1894, in their thesis. The two electromagnets were placed side by side, and the beams reflected from their mirrors received upon a prismatic mirror and thence sent to the screen. This is shown in plan in Figure 1. In this case the spots of light which appear on the screen when the mirrors are at rest are elongated into two vertical lines when currents are sent through the magnets, and these lines are drawn out into curves which flash across the screen when the prismatic mirror is rotated. As the motion of the springs is harmonic, these curves are sine curves, and thus bear no necessary resemblance to the original

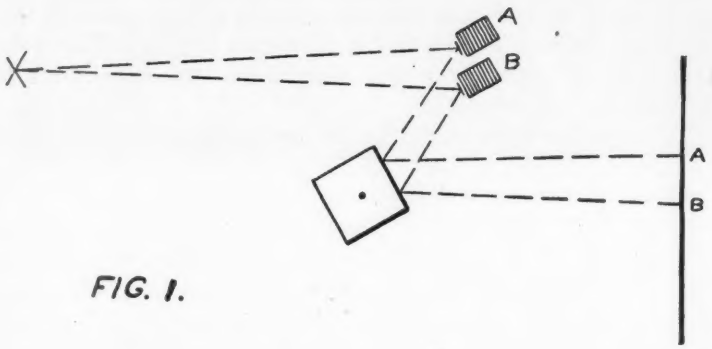


FIG. 1.

wave form. Figures 2 and 3 show some of these curves, whose wave length is, however, much less than that employed in measurements.

The theory of measurements is as follows: If the spots of light on the screen are in the same vertical line when the prismatic mirror is at rest, the curves produced by revolving it will have the same time origin, and will be parallel if they are in the same phase. Any time lag of one behind the other will be shown by a lateral shifting of the lagging curve ahead of the other, and if a variable inductance is inserted in the circuit of *B*, the *B*-curve will be seen to move farther and farther ahead of the *A*-curve as the inductance is increased. The difference of phase is thus evident to the eye, and to obtain a direct measure of it requires only a knowledge of the angle through which one curve must be shifted to bring it into parallelism with the other. This is readily expressible in degrees by finding the angle through which *B*

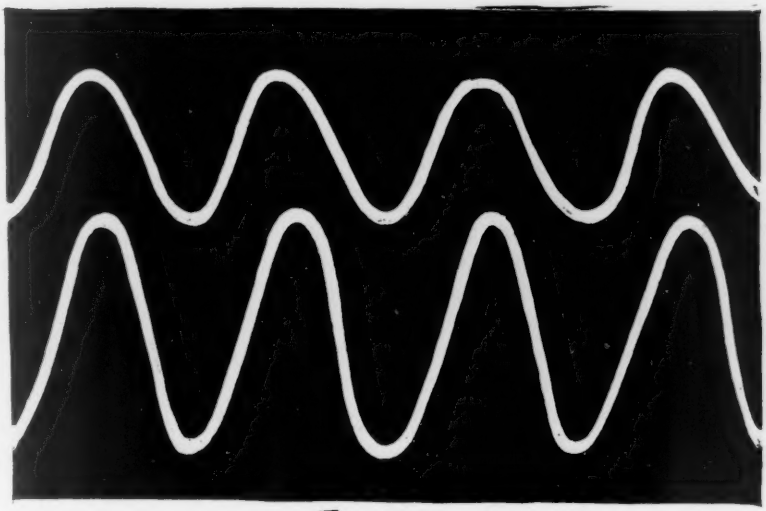


Fig. 2.

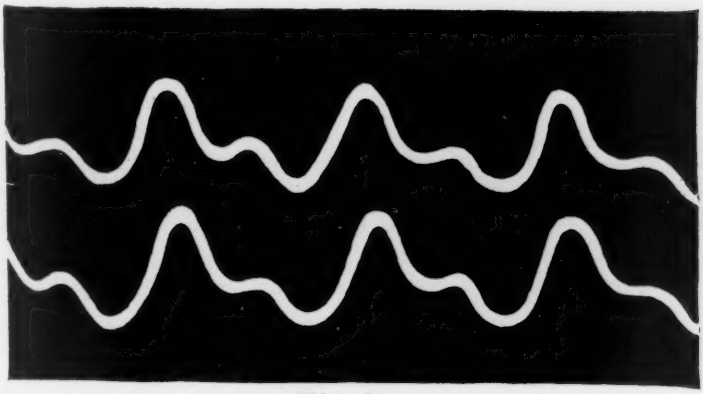


Fig. 3.

must be turned to bring E and F (Figure 4) into the same vertical, and then finding the angle through which B must be further turned to bring G and E into the same vertical, the first adjustment giving the portion of a wave length by which the two curves are separated, and the second the value of the whole wave length. Calling these quantities c and d, respectively, the phase difference of the curves on the screen is, in degrees, $360°/_{d}$.

One consideration is to be noted here, that as the vibrating springs execute a complete vibration for every reversal of the current, their vibration frequency is just twice that of the current, and hence the phase difference of the curves on the screen is twice that of the currents measured. The desired value is thus $180°/_{d}$.

As c and d are too small to be directly measured with precision, a multiplying device is necessary. Mirror B is turned by a gear wheel meshing with a small pinion which carries a long pointer moving over

FIG. 4.

a divided scale. With this device a wave length on the screen is covered by a displacement of 13 centimeters of the end of the pointer.

The procedure is as follows: With the prismatic mirror at rest, send the currents to be studied through A and B respectively. Turn B until the lines on the screen are in the same vertical, and take the pointer reading m. Start the revolving mirror, and when the curves are sufficiently elongated to permit convenient comparison turn the pointer until the curves are parallel, and take the reading n of the pointer. Turn the pointer still further until the B-curve has moved through an entire wave length and is again parallel to the A-curve, and record the new reading p of the pointer. Then the phase difference in degrees between the currents is

$$180\,\frac{m-n}{n-p}.$$

The results of these measurements plainly depend on the accuracy of bringing the curves into parallelism. This adjustment can be satis-

factorily made by moving *A* vertically until the curves are brought close together. As used in the following transformer measurements, the mirrors were of silvered glass and the outlines of the curves consequently indistinct from multiple reflection. This makes the adjustment less precise than might be expected if metallic mirrors were used, and partially accounts for the relatively large deviations attached to the results below.

Small Experimental Transformers.	Lag in Degrees.	Average Deviation.
Transformer with four secondaries, idle circuits open .	173.75	±0.38
Transformer with four secondaries, idle circuits closed .	177.0	....
Ring transformer, overwound with iron wire	172.29	±0.82
Ring transformer, closed secondary	176.50	±0.50
Two telephone induction coils in series	332.11	±0.84
Giving for each coil	166.06	±0.42

The following measurement affords a comparison of calculated with known values. The apparatus was applied to the measurement of the lag between the branches of a three-phase circuit. Perfect symmetry in the dynamo windings would give 120° in each branch, and in any case the sum of the three lags should be 360°. The values actually obtained are 119.22, 120.44, and 119.44. The sum of these is 359.00, the average deviation (0.92) in this case being not far from the real error.

Among the advantages of the method described above are: (a) Since the wave form does not enter the calculation, any source of periodic current may be employed, whether sinusoidal or not; (b) slight changes in the electromotive force do not impair the measurements, for their effect is only to vary the amplitude of the curves, a quantity of small consequence; (c) constancy in the speed of the revolving mirror is unnecessary, since irregularity affects both curves alike and does not alter their parallelism; (d) the approximate value of the lag can be seen at once, as well as the quadrant in which it lies; (e) the curves need not fall successively in the same

positions on the screen, as no measurements are made there, hence the speed of the revolving mirror need bear no definite ratio to that of the springs; (f) the apparatus is simple and easily constructed.

Figure 3 shows the form of the curves produced when the free vibration of the springs is the octave of the current frequency. These curves were obtained from the three-phase circuit before mentioned.

ROGERS LABORATORY OF PHYSICS,
June, 1894.

THE ELECTROLYTIC REDUCTION OF PARANITROBENZOIC ACID IN SULPHURIC ACID SOLUTION.

By A. A. NOYES, Ph.D., and A. A. CLEMENT, S.B.

Received October 19, 1894.

In an article published some time ago[1] we showed that, when nitrobenzene in sulphuric acid solution is submitted to the action of electrolytic hydrogen, the resulting product is not aniline, but the sulphonic acid of paramidophenol. That this reaction is characteristic of nitro compounds in general has since been proved by Gattermann,[2] who investigated a great variety of them — nitro-hydrocarbons, nitro-anilines, and nitro-acids — and found them all to undergo change in a similar way, the reduction of the nitro group being accompanied by a migration of one of its oxygen atoms to the para position. Only those compounds in which the para position is already occupied by another element or group than hydrogen form exceptions to this rule. Of such compounds only two were investigated — paranitroorthotoluidine and paranitrotoluene. The reduction product of the former consisted of diamidocresol (CH_3 (1), NH_2 (2), NH_2 (4), OH (5)), a migration of an oxygen atom to the *ortho* position having taken place. In the second case there was obtained a complex body which was shown[3] to result from the condensation of the primary reduction product, amidobenzyl alcohol, with a second molecule of nitrotoluene; thus, in this case, substitution of hydroxyl in the (methyl) group occupying the para position occurs. What reaction takes place seems therefore to depend on the nature of the para group, and the investigation of other para compounds in this direction is of considerable interest. We wish to describe here the reduction product of one of these, the paranitrobenzoic acid. We expected to obtain from it amidooxyben-

[1] Technology Quarterly, **6**, 62.

[2] Berichte der deutschen chemischen Gesellschaft, **26**, 1844.

[3] Berichte der deutschen chemischen Gesellschaft, **26**, 2810.

zoic acid, or possibly amidobenzoic acid itself; but, remarkably enough, neither of these substances is formed.

The paranitrobenzoic acid used was prepared[1] by boiling for one hour with return cooler portions of 20 grams of paranitrotoluene with 60 grams of potassium permanganate dissolved in two liters of water, filtering out the precipitate, concentrating the filtrate, and acidifying it. In this way 18 grams, 73 per cent. of the theoretical yield, were obtained.

The apparatus used for the electrolysis consisted of a small beaker, to the sides of which a large platinum electrode was closely fitted, and in which was placed a porous cup containing sulphuric acid and a small platinum electrode to serve as the positive pole. The solution, made by dissolving 12 grams of the nitrobenzoic acid in 100 grams of warm concentrated sulphuric acid, was poured into the beaker, which was surrounded with asbestos to prevent loss of heat, and a current of one ampere passed through for twenty-four hours.

To isolate the product the solution was diluted with water, cooled, and filtered. The precipitate was found to be very little soluble even in boiling water, showing the absence of sulphates of bases. It was treated with sodium carbonate solution, the residue consisting of sulphur was filtered out, and the filtrate was acidified. A voluminous precipitate separated; it was collected on a filter, and washed first with water, then with alcohol and ether to remove any unchanged nitrobenzoic acid. Four grams of product were thus obtained. Its properties and analysis showed it to be paramidophenolsulphonic acid. It was only very slightly soluble in boiling water and insoluble in alcohol and ether. It reduced silver nitrate solution in the cold, with production of a purple color. The solution of its salts turned brown rapidly in the air. It gave the following results on analysis:

	Found.[2]	Calculated for $C_6H_3NH_2OHSO_3H$.
C	37.70	38.09
H	3.75	3.70
SO_3	42.40	42.33

To give further proof of the identity of the acid, some of it was heated to 175° in a closed tube with concentrated hydrochloric acid.

[1] Berichte der deutschen chemischen Gesellschaft, **10**, 580.

[2] 0.3964 gms. substance gave 0.5479 gms. CO_2 and 0.1336 gms. H_2O; 0.4356 gms. substance gave 0.5380 gms. $BaSO_4$.

At this temperature the sulphonic group was split off, as is the case with the paramidophenolsulphonic acid.[1] The hydrochlorate, which crystallized out on cooling, was filtered off, dried, and boiled with a large excess of acetic anhydride. The resulting product after crystallization from water showed a melting point of 152°, identical with that of diacetylparamidophenol.

The electrolytic reduction product of paranitrobenzoic acid is, therefore, paramidophenolsulphonic acid, the tendency of the oxygen atoms to assume the para position being great enough to expel the carboxyl group originally occupying it.

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[1] Technology Quarterly, 6, 64.

SOME OBSERVATIONS ON THE GROWTH OF DIATOMS IN SURFACE WATERS.

By GEORGE C. WHIPPLE, S.B., Biologist in Charge, Laboratory of the Boston Water Works; Biologist to the Water Works of Lynn.

Read October 25, 1894.

For more than a century the study of the diatoms has been a fascinating pastime. Much has been written on the beauty of their form and markings, their animal or vegetable nature, their classification, and their peculiar spontaneous movements. Their study is now becoming one of practical importance, because it has been found that these little plants are often present in large numbers in the ponds and reservoirs of our public water supplies, and that they give rise to unpleasant tastes and odors in the water.

On account of the important effects produced by these and other micro-organisms, considerable attention is now being given to the microscopical examination of water. The most extensive series of such examinations thus far published are those of the Massachusetts State Board of Health[1] and those made at the biological laboratory of the Boston Water Works.[2] The former are valuable because of their wide range, covering as they do all the public water supplies of the State. The value of the latter lies in the fact that the examinations have been made at very frequent intervals, and that in every way the work has been carried into great detail. The temperature readings which accompany each sample are also of great value. It is the purpose of this article to review some of the data obtained from these two sources in regard to the *Diatomaceæ*, particularly with reference to their seasonal distribution.

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[1] See Annual Reports of the Massachusetts State Board of Health for the years 1890 to 1892, inclusive. Also special Report of the State Board of Health on Examinations of Water Supplies, 1890.

[2] See Annual Reports of the Boston Water Board for the years 1890 to 1893, inclusive.

It will be but a slight digression for me to refer briefly to the biological work of the Boston Water Works. The Biological Laboratory was established at the Chestnut Hill Reservoir in the fall of 1889 by Mr. Desmond FitzGerald, Resident Engineer and Superintendent of the Western Division; and since January, 1890, the work has been carried on by the writer under his direction. So far as I am aware, this was the first laboratory established by any city for the purpose of making systematic biological examinations of its water supply. Ever since the work was inaugurated weekly examinations have been made of samples of water collected from all parts of the supply, *i.e.*, from the brooks, ponds, storage reservoirs, and service taps. Thus we are enabled to give a history of the water from the time it falls from the clouds until it reaches the mouths of the consumers. Since the first of January, 1890, more than 12,000 microscopical and more than 5,000 bacteriological examinations have been made at the laboratory. Besides the regular examinations numerous special investigations are constantly being made. The laboratory is provided with an excellent dark room, and photomicrographs of most of the important micro-organisms have been obtained.

The diatoms, or technically the *Diatomaceæ*, are minute plants forming a group of microscopic *Algæ* remarkable for their siliceous epiderm and for their variety of form and markings. They are unicellular, though in some genera the cells are united into filaments. The cell contents consist of a membrane, cell sap, nucleus, chromatophore plates, and sometimes oil globules and starch grains. Living diatoms are surrounded by a gelatinous envelope, which, on account of its transparency, can be seen only by adding coloring matter to the surrounding fluid. Of the cell contents biologists are at the present time most interested in the oil globules, because it is being proved that the oils present in the micro-organisms are the direct cause of many of the bad tastes and odors of certain drinking waters.

Of the one hundred and more genera into which the diatoms have been classified there are not more than twenty that are commonly found in our water supplies, and only six have, thus far, been found to be of practical importance, namely, *Asterionella*, *Tabellaria*, *Melosira*, *Synedra*, *Stephanodiscus*, and *Diatoma*. Some of the other genera occasionally met with are *Cyclotella*, *Cymbella*, *Epithemia*, *Fragilaria*, *Gomphonema*, *Meridion*, *Navicula*, *Nitzschia*, *Pleurosigma*, *Schizonema*, *Stauroneis*, and *Surirella*.

The six most important genera are not always observed in the same reservoir. Generally there are certain diatoms peculiar to certain ponds. Lake Cochituate, for instance, often contains large growths of *Asterionella*, *Tabellaria*, and *Melosira*, and smaller growths of *Synedra* and *Stephanodiscus*. Basin No. 3 contains *Asterionella*, *Tabellaria*, and *Synedra*, but no *Stephanodiscus* nor *Melosira*. In Basin No. 2 only *Synedra* and *Cyclotella* are found. Fresh Pond, Cambridge, is famous for its *Stephanodiscus*, and *Diatoma* is often very abundant in the Lynn waters. Furthermore, there are ponds where diatoms are never found, except in very small numbers at rare intervals, while in neighboring ponds they may be present in such large numbers that a bottle of the water, when held towards the light, has a silvery, glistening appearance.

Just why diatoms grow in some ponds and not in others it is at present impossible to say. A suggestion as to the reason will be offered later on in this paper, and as the local distribution is found to be closely connected with the seasonal distribution these two subjects will be treated together.

In an article by G. N. Calkins,[1] on "The Seasonal Distribution of Microscopical Organisms in Surface Waters," it has been shown that there are two seasons of the year, namely, the spring and the late fall, when the diatoms increase prodigiously. The spring maximum occurs in April, and the fall maximum in December. During the summer and the greater part of the winter diatoms are sometimes found, but only in small numbers.

My own observations on the reservoirs of the Boston Water Works confirm these results. I have noticed that, while it is true that diatoms appear with considerable regularity each spring and fall, the genera which appear at any given season are not always the same. If we consider, for example, the spring growths in Lake Cochituate, we find that in 1890 the *Asterionella* first appeared, and that this growth was soon followed by one of *Tabellaria*. In 1891 the growth was chiefly *Asterionella*, *Melosira* appearing about the same time but not developing to any great extent. In 1892 *Melosira* was the predominant diatom; in 1893, *Melosira* and *Asterionella;* and in 1894, *Tabellaria*, *Asterionella*, and *Melosira*. It would be a matter of great

[1] G. N. Calkins: The Seasonal Distribution of Microscopical Organisms in Surface Waters. Twenty-fourth Annual Report Massachusetts State Board of Health, 1892.

interest to be able to account for these occurrences; we might then be able to control the conditions which favor the growth of one genus and retard the growth of another. We should like to keep down the *Asterionella*, the diatom which is most active in producing tastes and odors in the water. In case we could not get rid of the diatoms entirely, we would willingly accept a growth of *Synedra* if we could keep out the *Asterionella* and *Tabellaria*. So far as I know, *Synedra* has never been the cause of any trouble.

A comparison of the microscopical examinations of the different reservoirs of the Boston Water Works shows that Basins No. 2 and

TABLE NO. I.

AMORPHOUS MATTER.

Average of weekly examinations of samples from the surface, mid-depth, and bottom for a period of four years.

Locality.	Number of Standard Units[1] per cc.
Lake Cochituate	432
Basin 3	407
Basin 2	322
Basin 4	228

No. 4 never have extensive diatom growths, but that in Basin No. 3 and Lake Cochituate these plants develop regularly in the spring and fall. It is possible that the reason for this difference lies in the different conditions of the bottoms of these reservoirs. When Basin No. 4 was constructed all the peat, turf, etc., was carefully removed from the bottom. This was done over a large part of Basin No. 2. In Basin No. 3 the stripping was not as thoroughly done, and the bottom was originally more swampy. Lake Cochituate is a deep, natural pond with a muddy bottom. On account of this soft bottom with its organic matter the "amorphous matter" has always been higher in Lake Cochituate than in Basins No. 2 and No. 4. This is shown by Table No. I.

[1] One Standard Unit represents a surface area of four hundred square microns.

The fact that the diatom growths are in some way connected with the muddy bottoms of ponds is also suggested by their seasonal distribution. It has been observed that the spring growths occur at about the same time in Basin No. 3 and in Lake Cochituate, but that the fall growths always take place later in Lake Cochituate than in Basin No. 3. The reason for this is to be found in the phenomenon of "stagnation."

It is well known that in ponds which are more than 25 or 30 feet deep the temperature of the water at the bottom remains quite constant during the summer, while the temperature of the surface water rises and falls with the temperature of the air. The consequence is that the lower strata of water remains stagnant during the summer; that is to say, there are no vertical currents in the water below the depth where the wind ceases to keep the water in motion. In the fall the surface water cools until it reaches the same temperature as the water at the bottom. Then when the density of the water is the same at all depths there is a stirring up; the lower layers are brought to the surface, and the light, flocculent, amorphous matter, always abundant at the bottom when the soil is muddy, is distributed through the water. During the winter, when the surface of the water is frozen, there is another period of stagnation, due to the fact that the temperature of the water at the bottom tends to remain at the point of maximum density (39.2°F.), while the surface temperature sinks nearly to the freezing point. The winter stagnation takes place in both deep and shallow ponds.

The stagnation of the lower layers is also indicated by the color of the water. In Lake Cochituate the water at the bottom acquires a dark reddish brown color during the stagnation periods, most marked, of course, during the summer, when the period is long. At the time of the "turning over" this dark water is distributed through the vertical, the result being to increase the color at the surface. These facts are shown by diagram on Plate I.

It will be noticed that there are two periods of the year, each about six weeks long, when the water is in circulation from top to bottom. It is during these periods that the diatoms develop. Microscopical examinations have shown that both in Basin No. 3 and in Lake Cochituate the diatom growths occur soon after stagnation ends. The *Asterionella*, for instance, generally appears about one week after the turning over. It then increases, reaching its maximum growth in from twenty-five to fifty days.

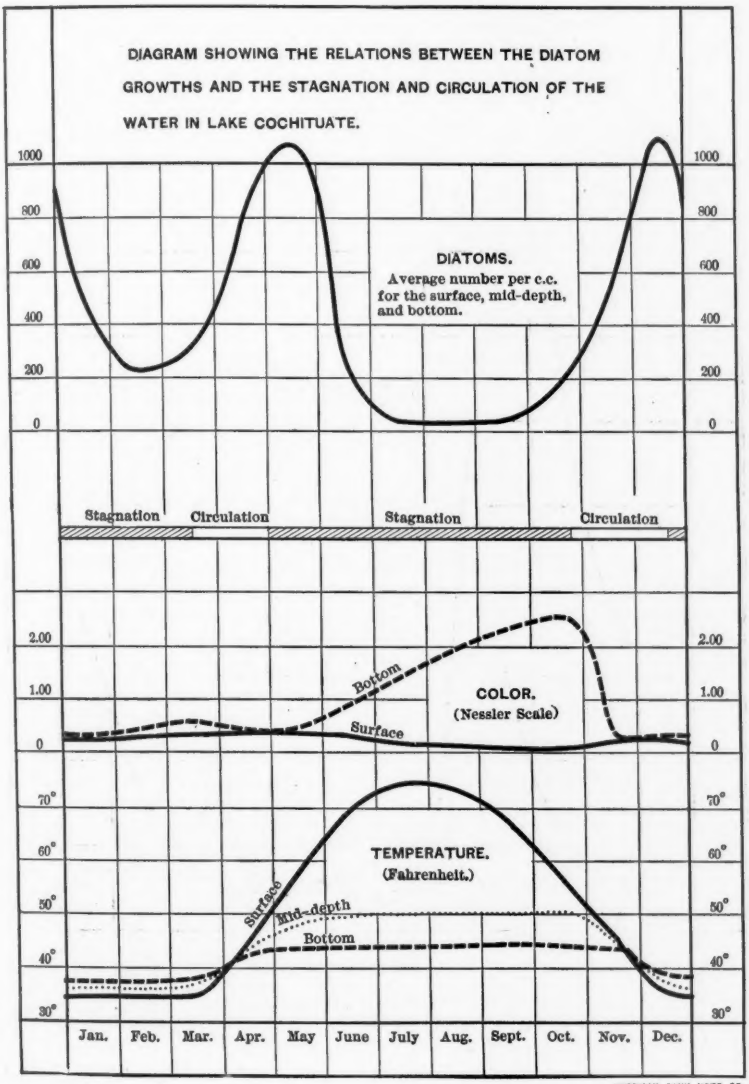


DIAGRAM SHOWING THE RELATIONS BETWEEN THE DIATOM GROWTHS AND THE STAGNATION AND CIRCULATION OF THE WATER IN LAKE COCHITUATE.
1000
800
600
400
200
0
DIATOMS.
Average number per c.c. for the surface, mid-depth, and bottom.
Stagnation
Circulation
Stagnation
Circulation
2.00
1.00
0
Bottom
Surface
COLOR.
(Nessler Scale)
70°
60°
50°
40°
30°
TEMPERATURE.
(Fahrenheit.)
Surface
Mid-depth
Bottom
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
AMERICAN BANK NOTE CO.

PLATE I.

The bottom temperature of Lake Cochituate is considerably lower than the bottom temperature of Basin No. 3 during the summer months, on account of its greater depth; hence its turning over occurs later in the year. This explains why the fall growth of diatoms occurs later in Lake Cochituate. The drawing down of Basin No. 3

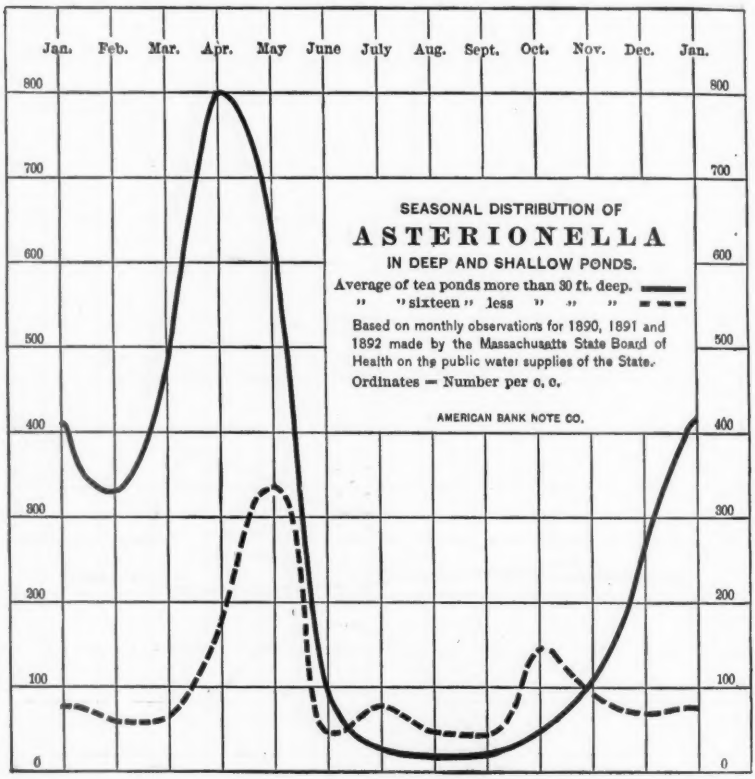


PLATE II.

each season for the supply of the city also affects the time of the turning over of that reservoir.

The examinations of the State Board of Health furnish corroborative evidence that the seasonal distribution of diatoms is controlled by the circulation and stagnation of the water. This may be seen by comparing the diatom growths in deep and shallow ponds. On the

assumption that diatoms grow best immediately after the turning over, we should expect to find in the deep ponds two periods of diatom growth — one in the spring, following the winter stagnation; and one in the fall, after the summer stagnation. In the case of shallow ponds, however, we should expect to find a spring growth following the winter stagnation, and for the rest of the year a uniform or irregular distribution. This is found to be the case. Of twelve ponds and reservoirs more than 30 feet deep, eleven show a well-defined spring and

TABLE NO. II.

AVERAGE NUMBER OF ASTERIONELLA IN A CUBIC CENTIMETER OF WATER.

Based on Monthly Observations for Three Years.

Month.	Average of Eleven Ponds and Reservoirs over 30 feet deep.	Average of Sixteen Ponds and Reservoirs less than 30 feet deep.
January	410	77
February	331	58
March	475	61
April	799	190
May	617	332
June	89	48
July	29	75
August	27	46
September	26	42
October	47	138
November	103	93
December	275	68

fall growth, while in one instance the growth was uniformly distributed; and of seventeen ponds and reservoirs less than 30 feet deep, eleven have diatom growths appearing at irregular intervals but having a slight spring maximum, while four have both a spring and fall growth.

Table No. II shows a comparison between the deep and shallow ponds with regard to the number of *Asterionella* found each month. The figures were obtained by averaging monthly observations extend-

ing over a period of three years. The first column is made up of averages of eleven ponds over 30 feet deep, and the second column of averages of sixteen ponds less than 30 feet deep. These results are shown by diagram on Plate II. The depth of 30 feet was selected as the dividing line between the deep and shallow ponds because stagnation does not ordinarily occur in ponds having less depth than that. It is probable, however, that the four shallow ponds referred to in the preceding paragraph as having spring and fall growths of diatoms have also periods of winter and summer stagnation.

An examination of Plate II shows that the diatom growths are most extensive in deep ponds. In those ponds, also, the spring and fall maxima are the most marked, and there is almost an entire absence of diatoms during the summer months. The spring growth is observed in the shallow ponds, and there is a slight indication of a fall growth. During the summer the curve for the shallow ponds is higher than for the deep ponds, and is somewhat irregular. It will also be noticed that in the deep ponds the spring growth occurs earlier and the fall growth later than in the shallow ponds. This is what might be expected from what we know of the phenomenon of stagnation.

In order to find the reason for the rapid development of diatoms after the turning over of the water, let us look at some of the chemical analyses. In Table No. III will be found a summary of the State Board of Health analyses for Lake Cochituate and Basins 2, 3, and 4 for a period of about five years.

Bearing in mind that Lake Cochituate and Basin No. 3 support immense growths of diatoms and that Basins No. 2 and No. 4 do not, it will be seen that the mineral constituents as indicated by the chlorine, fixed residue, hardness, and nitrates are higher in those cases where diatoms abound. The free ammonia and nitrites are also somewhat higher. On the other hand, the color, loss on ignition, and albuminoid ammonia do not seem to bear any direct relation to the diatom growths.

Reasoning by what is known of the higher plants, we may assume that the most important factor is that of the nitrates, and we should expect, therefore, that the nitrates would be high during or just preceding a growth of diatoms.

That this is the case is shown by Table No. IV, where the chemical analyses are tabulated by periods corresponding to the rise, fall, and absence of diatoms. Each of these periods is subdivided. The first

subdivision includes the time when the surface of the water was frozen; and the second, the period of open water. This subdivision is important because it has been found that no extensive growths of diatoms occur when the surface of the water is covered with ice.

During the period of diatom development the nitrates were .0240 in Lake Cochituate, and .0200 in Basin No. 3. While the diatoms were disappearing, yet above 200 per cc., and when there were fewer

TABLE NO. III.

CHEMICAL ANALYSES.

Means of Monthly Analyses for Five Years. (Parts per 100,000.)

	Lake Cochituate.	Basin 3.	Basin 2.	Basin 4.
Color	.20	.75	.89	.67
Residue, total	4.66	5.07	4.31	3.51
Residue, loss on ignition	1.35	1.90	1.82	1.53
Residue, fixed	3.32	3.18	2.48	1.99
Chlorine	.46	.39	.28	.22
Albuminoid Ammonia, suspended	.0034	.0045	.0038	.0034
Albuminoid Ammonia, dissolved	.0144	.0215	.0201	.0176
Free Ammonia	.0018	.0026	.0008	.0011
Nitrites	.0002	.0002	.0001	.0001
Nitrates	.0113	.0171	.0085	.0065
Hardness	2.07	1.80	1.05	1.19

than 200 per cc., the nitrates were high during the time when the surface was frozen; but they were much lower during the period of open water. This seems to indicate that diatoms require both nitrates and a free circulation of air. If either is lacking they will not develop. This fact throws some light on their seasonal distribution. In the winter air is lacking; in the summer nitrates are low; but in the spring and fall nitrates and air are both present. That diatoms need air has already been shown by laboratory experiments, but whether it is the oxygen or the carbonic acid gas of the air has not been determined.

It is probable, also, that the effect of light has some bearing on

TABLE NO. IV.

CHEMICAL ANALYSES. (Parts per 100,000).

DIATOMS.	Condition of Surface.	Fixed Solids.		Albuminoid Ammonia (Filtered).		Free Ammonia.		Nitrites.		Nitrates.	
		Lake Cochituate.	Basin 3.	Lake Cochituate.	Basin 3.	Lake Cochituate.	Basin 3.	Lake Cochituate.	Basin 3.	Lake Cochituate.	Basin 3.
Increasing	Frozen.	....	....	....	....	....	....	....	....	....	....
Increasing	Not frozen.	3.44	2.92	.0143	.0217	.0027	.0016	.0002	.0001	.0240	.0200
Above 200 per cc., but decreasing	Frozen.	3.62	....	.0141	....	.0026	....	.0002	....	.0280	....
Above 200 per cc., but decreasing	Not frozen.	3.00	3.26	.0137	.0256	.0011	.0010	.0003	.0002	.0110	.0103
Below 200 per cc. . .	Frozen.	3.15	3.25	.0129	.0142	.0007	.0043	.0002	.0002	.0215	.0296
Below 200 per cc. . .	Not frozen.	3.27	3.22	.0147	.0210	.0007	.0020	.0003	.0002	.0104	.0096

their growth. It has been proved that diatoms will not develop in the dark, and it is said that bright sunlight will kill them.

Table No. IV also shows that the fixed solids, dissolved albuminoid ammonia, and the free ammonia bear little relation to the diatom growths. If, now, we compare Table No. IV with Table No. V, which gives the amount of nitrates present in Basins No. 2 and No. 4 during the periods corresponding to the increase, decrease, and absence of diatoms in Basin No. 3, we shall see, perhaps, why these basins do not support large diatom growths. When the diatoms were increasing in

TABLE NO. V.

CHEMICAL ANALYSES. (Parts per 100,000.)

DIATOMS IN BASIN 3.	Condition of Surface of Basins 2 and 3.	Nitrates.	
		Basin 2.	Basin 4.
Increasing	Frozen.	....	....
Increasing	Not frozen.	.0110	.0070
Above 200 per cc., but decreasing	Frozen.	....	....
Above 200 per cc., but decreasing	Not frozen.	.0080	.0018
Below 200 per cc.	Frozen.	.0160	.0108
Below 200 per cc.	Not frozen.	.0051	.0058

Basin No. 3, the nitrates were only .0110 in Basin No. 2 and .0070 in Basin No. 4, as compared with .0200 in Basin No. 3 and .0240 in Lake Cochituate, and during two of the other periods the nitrates were still lower. During one period they rose to .0160 in Basin No. 2 and .0108 in Basin No. 4; but at that time the surface was frozen and there was no circulation of air, and consequently no growth.

As a confirmation of the theory that diatoms require nitrate food we have the following analyses from the State Board of Health. Eighteen ponds and reservoirs in which *Asterionella* growths reached 1,000 per cc. gave .0188 as the yearly average of the nitrates present; six ponds and reservoirs where the growth was between 500 and 1,000 per cc. gave an average of .0091; and for sixteen ponds and reservoirs where the *Asterionella* were less than 500 per cc. the average of the nitrates was .0080. Of the eighteen ponds and reservoirs which make

up the average .0188, five were less than .0080; but these ponds had the nitrates considerably above .0100 during the periods when the diatoms were increasing.

It must not be supposed, however, that the diatoms live entirely on nitrates. Other food materials are, of course, necessary; and it is possible that the diatoms may have the power of assimilating nitrogen in other forms than the nitrates. Culture experiments are now being conducted at the laboratory of the Boston Water Works which may throw some light on this question.

We have now to consider the condition of the water at the bottom of the deep ponds. This is shown by Table No. VI, where analyses are given for the surface and bottom of Lake Cochituate, Basins No. 3 and No. 4, and Jamaica Pond during the stagnation periods. In Lake Cochituate, Basin No. 3, and Jamaica Pond there is seen to be a large amount of decaying organic matter at the bottom. This is shown by the high free ammonia. On account of the absence of oxygen at the bottom the decomposition could not be carried beyond that stage. Iron, manganese, and silicon were also highest at the bottom. In the case of Basin 4, which was stripped of its peat, loam, etc., before filling, there is little decomposable organic matter at the bottom.

At the turning over of the water the free ammonia is brought to the surface, where the bacteria, supplied with plenty of oxygen, complete the decomposition, changing the nitrogen to the nitrate form. At the same time, also, it is probable that the diatoms or their spores are brought up from the bottom and scattered through the water, where, finding an abundance of nitrates and air, they develop rapidly. If, however, there is no free ammonia at the bottom, as is ordinarily the case in properly prepared reservoirs, no nitrates will be found at the time of the turning over, and consequently no diatom growths will appear.

We thus have strong evidence in favor of the removal of the top soil when preparing a reservoir for the storage of water. This position has already been taken by some of the most eminent of our engineers. Its practice ought to be universal.

The question of the rate of increase of micro-organisms is an important one. It is especially interesting in the case of diatoms, because it has been the subject of numerous controversies. It has generally been assumed that the increase takes place in accordance with the law of geometrical progression, *i.e.*, starting with a single

TABLE NO. VI.

CHEMICAL ANALYSES. (Parts per 100,000).

Locality.	Date.	Color.	Residue on Evaporation.			Chlorine.	Nitrogen.					Oxygen Consumed.	Hardness.	Dissolved Oxygen.	Iron.	Manganese.	Silica.
			Total.	Loss on Ignition.	Fixed.		Albuminoid Ammonia.		Free Ammonia.	As Nitrites.	As Nitrates.			Per cent. Sat.			
							Unfiltered.	Filtered.									
Lake Cochituate, Surface	Sept. 28, 1891.	.12	4.70	1.15	3.55	.44	.0134	.0116	.0002	.0002	.0020	.34	1.82	100	.11	.04	.31
Lake Cochituate, Bottom (65 feet)	Sept. 28, 1891.	3.40	8.05	2.25	5.80	.42	.0244	.0186	.0736	.0005	.0020	1.07	1.98	0	.96	.21	.86
Lake Cochituate, Gate House	Nov. 2, 1891.	.25	4.60	1.10	3.50	.46	.0144	.0100	.0044	.0001	.0200	....	1.9	....	....	....	....
Basin No. 3, Surface	Aug. 19, 1891.	.35	6.25	2.40	3.85	.45	.0224	.0214	.0008	.0002	.0020	.65	1.55	85.88	.17	.03	....
Basin No. 3, Bottom (25 feet)	Aug. 19, 1891.	3.00	7.20	2.45	4.75	.44	.0310	.0250	.0496	.0004	.0020	1.20	1.96	0	.70	.16	....
Basin No. 4, Surface	Aug. 19, 1891.	.42	3.65	1.80	1.85	.25	.0134	.0122	.0002	.0002	.0030	.73	1.14	84.50	.06	.03	....
Basin No. 4, Bottom (35 feet)	Aug. 19, 1891.	.55	3.20	1.45	1.75	.28	.0118	.0110	.0008	.0002	.0040	.68	1.22	15.10	.22	.06	....
Basin No. 4, Surface	Oct. 1, 1891.	.35	3.25	1.85	1.40	.23	.0178	.0146	.0000	.0000	.0070	....	.09	....	....	....	....
Jamaica Pond, Surface	Aug. 14, 1890.	....	....	....	....	....	.0362	.0220	.0000	.0000	.0030	....	....	....	....	....	....
Jamaica Pond, Bottom (50 feet)	Aug. 14, 1890.	....	....	....	....	....	.0460	.0350	.4720	.0000	.0150	....	....	....	....	....	....
Jamaica Pond, Surface	Nov. 27, 1889.	....	....	....	....	....	.0246	.0180	.0640	.0009	.0120	....	....	....	....	....	....
Jamaica Pond, Bottom (50 feet)	Nov. 27, 1889.	....	....	....	....	....	.0236	.0174	.0712	.0009	.0150	....	....	....	....	....	....

cell, this cell after a certain time divides into two, each of which after another interval of time divides into two more, and so on, so that after n intervals of time, the number of cells would be ar^n, where $a = 1$, and $r = 2$.

There are some writers, following Otto Müller,[1] who have claimed that the increase takes place more slowly than this, because, they say, when a cell divides the smaller of the resulting cells does not have the same power of reproduction as the larger on account of lacking the necessary thickness of connective band. My own observations seem to show that the diatoms do increase substantially in accordance with the laws of geometrical progression, and that the ratio varies between 1.3 and 2.0 per week, the average ratio for ten growths of *Asterionella* covering a period of thirty-five weeks being 1.58. The corresponding ratio for *Tabellaria* was 1.56. We may say, in a general way, that during a vigorous growth the diatoms increase at the rate of about 50 *per cent.* each week.

On Plate III will be found a diagram showing the rate of growth of *Asterionella* in Lake Cochituate. The full lines represent the diatom growths. The broken line represents the equation $l = ar^n$, where $a = 1$, $r = 1.58$, and $n =$ the number of weeks. The number of weeks are plotted as abscissæ, and the number of *Asterionella* per cc., as ordinates.

A growth of *Synedra* in Basin No. 2, lasting ten weeks, had a slower rate, the average ratio being 1.3 per week. In this growth the *Synedra* multiplied more rapidly at first than they did later on. The ratio for the first half was 1.4, and for the second half, 1.2.

But to say that the diatoms increase slowly and regularly does not tell the whole story. Oftentimes they develop with extraordinary rapidity, sometimes jumping from 132 to 1,575 per cc. in a single week, as *Asterionella* did in Walden Pond, Lynn, Massachusetts, in October, 1893. The reason for these sudden and enormous developments is not known. We have tried to associate them with some sudden increase in the amount of food material. But though we have been thus far unsuccessful, it is quite probable that that is the cause. It is possible, as some have suggested, that it is in some way connected with the formation of sporangial frustules, the result of conjugation.

[1] Dr. H. Van Heurck. Synopsis des Diatomées en Belgique, p. 13.

This phenomenon is an interesting one, but comparatively little is known about it. The theory is this. The diatoms grow smaller as they subdivide. Finally, after reaching a certain size, or after a certain weakening of the power of subdivision, a conjugation takes place

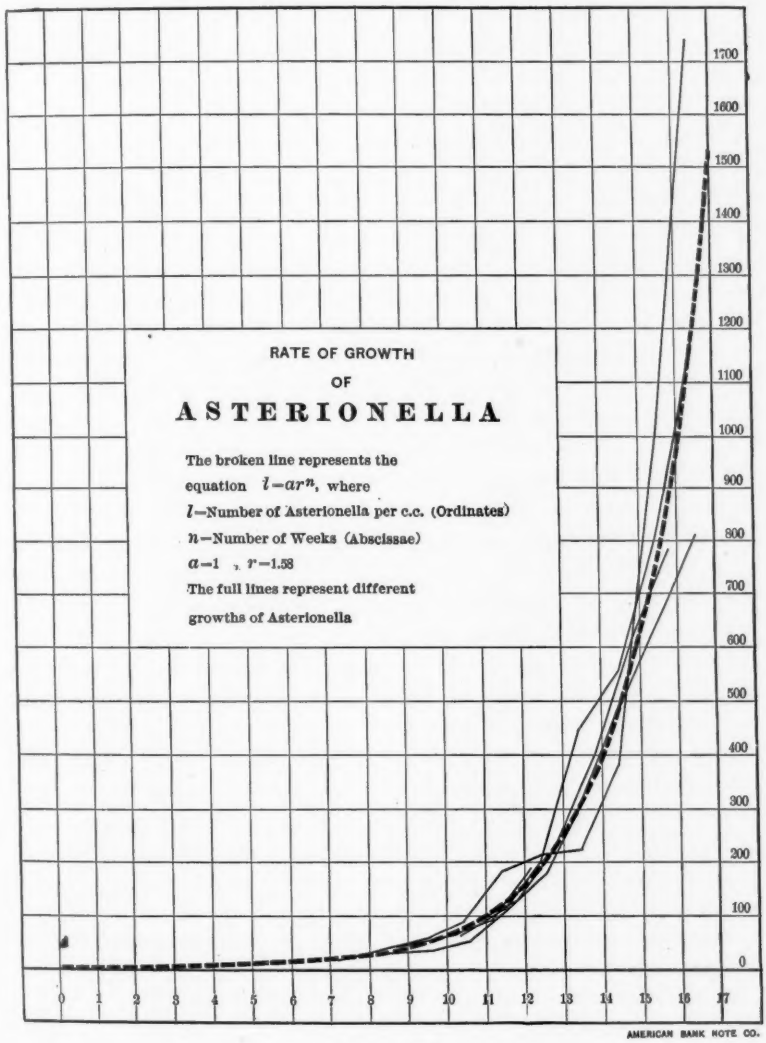


PLATE III.

between two of the cells, the result being a sporangial frustule, from which a larger cell is produced. This divides and subdivides, the new cells growing smaller and smaller, until a new conjugation is necessary. Among certain genera artificially cultivated this process has been observed. I have found the sporangial frustules of *Melosira* in a jar of water which had been standing for a few weeks in the laboratory, and I have seen *Asterionella* in what appeared to be a conjugating form; but the facts do not warrant any positive statements. The decrease in the size, however, has been repeatedly observed; it is especially marked in *Stephanodiscus* and *Cyclotella.*

Thus far we have considered only the increase of the diatoms. They probably cease to develop when their food supply is cut off. This has already been shown by Table No. IV. The periods of decreasing growth are marked by a deficiency of air or nitrates. It is to be regretted that more determinations of nitrates have not been made in connection with the development of diatoms. With frequent observations it might be possible to predict the extent of growth and the time when the growth would culminate. Such information might be of practical value.

The decrease of diatoms is ordinarily quite abrupt, but they sometimes linger over a long period. Generally a rapid growth is followed by a rapid fall. During the period of decline the cells are often broken up; the brown coloring matter is less abundant, and is frequently massed together in spots instead of being spread out in plates over the cell; occasionally it has a slight greenish color. Empty cells are always abundant during the declining period. During an increasing growth the diatoms are generally most abundant at the surface of a pond; during the period of decline they are usually more abundant towards the bottom.

As to the effect of temperature on diatoms, our observations indicate that the variations of temperature usually met with in the ponds of this climate have comparatively little influence on their growth, certainly not enough to account for their seasonal distribution. Diatoms grow well both in summer and winter, provided food is plenty. Vigorous growths have been observed at temperatures ranging from 35° to 75° F. The mean temperature at which the maximum *Asterionella* growths have been observed in Lake Cochituate is 50° F., the temperatures of the different growths, however, varying from 35° to 67°. The temperature of the water affects the diatoms indirectly by producing stagnation, as has already been pointed out.

RÉSUMÉ.

In this paper I have endeavored to show:

1. That the growth of diatoms in ponds is directly connected with the phenomenon of stagnation; that their development does not occur when the lower strata of water are quiescent, on account of greater density, but rather during those periods of the year when the water is in circulation from top to bottom.

2. That diatoms flourish best in ponds having muddy bottoms.

3. That in deep ponds there are two well-defined periods of growth — one in the spring and one in the fall; that in shallow ponds there is usually a spring growth but no regular fall growth, and that other growths may occur at irregular intervals as the wind happens to stir up the water.

4. That the two most important conditions for the growth of diatoms are a sufficient supply of nitrates and a free circulation of air, and that both these conditions are found at those periods of the year when the water is in circulation.

5. That while temperature has possibly a slight influence on the growth of diatoms, it is of so little importance that it does not affect their seasonal distribution.

6. That the increase of diatoms takes place substantially in accordance with the law of geometrical progression, and that the cessation of their growth is caused by the diminution of their food supply.

In conclusion I desire to record my appreciation of the kind advice of Prof. W. T. Sedgwick and Mr. Desmond FitzGerald, C. E., and I wish also to express my thanks to Mr. W. F. Murphy, who has assisted me in the preparation of this paper.

CLOSE SIZING BEFORE JIGGING.[1]

By ROBERT H. RICHARDS, S.B.

Received October 24, 1894.

THE extent to which sizing by sieves should be carried, as a preliminary to the separation, by jigging, of minerals of different specific gravities, has been a matter of controversy for many years. The subject has been investigated by several authorities, yet the ground does not seem to have been completely covered, nor are the questions involved entirely settled. For my present purpose I shall refer to but three investigators — Rittinger, Munroe, and Hoppe.

In seeking additional light, I have gone over part of the old ground which has been considered satisfactorily settled; and since these preliminary tests have thrown light on some points, they have been included in this paper.

In the investigations here described, I have confined myself, for several reasons, wholly to small sizes — grains of 0.1 inch in diameter and less. Rittinger's work was mainly done upon larger sizes, and there is much need among millmen of information concerning the smaller sizes. Moreover, these sizes brought the investigation within the means at my disposal.

The laws that have been claimed as the laws of jigging by the several authorities are:

1. The law of equal-settling particles.
2. The law of interstitial currents.
3. The law of acceleration.
4. The law of suction.

The first of these has been considered by investigators generally to be the most important of all, and the larger part of the work of jigging is thought to be governed by it. But that it does not cover the whole of jigging is clear to all; and to account for the increased

[1] Read at the Virginia Beach Meeting of the American Institute of Mining Engineers, February, 1894.

efficiency, which we may call the extra jigging-catch, the other three laws have been advanced.

The investigation described in this paper was undertaken to determine, as far as possible, to what extent each of the four laws contributes towards the results of jigging. The discussion will be taken up in the order indicated above.

I. Equal-Settling Particles.

If we drop into a deep vessel filled with water an unsized product containing particles, say, of galena and quartz, which have been thoroughly wetted, and all of which will pass through a limiting-sieve of ten meshes to the linear inch, we shall find that, after the short interval of acceleration, each particle will fall at its maximum velocity towards the bottom. These velocities, if the particles do not interfere with each other, and if they are all cubes or spheres, will depend upon two things, namely, the specific gravity and the size of the grains. Of two particles of equal size, but different specific gravity, the heavier will fall the faster. Of two particles of like specific gravity, but different diameter, the larger will fall the faster. Evidently, therefore, any larger particle of the quartz will have the same velocity as a certain smaller-sized grain of galena. These two grains are said to be equal-settling particles.

Rittinger gives, in his treatise, three formulas to represent the relation between diameter of grains and rate of falling in water for irregular-shaped grains:

$$V = 2.73\sqrt{D(\delta - 1)}, \text{ for roundish grains.}$$
$$V = 2.44\sqrt{D(\delta - 1)}, \text{ for average grains.}$$
$$V = 2.37\sqrt{D(\delta - 1)}, \text{ for long grains.}$$
$$V = 1.92\sqrt{D(\delta - 1)}, \text{ for flat grains.}$$

In which V is the velocity in meters per second; D, the diameter of particles in meters; and δ the specific gravity of the minerals.

From the formula for the average he computes the ratio of the diameters of quartz and galena particles that will be equal-settling in water. Taking the specific gravities as determined by me, viz., for quartz, 2.640, and for galena, 7.586, and using his formula for the average grain, we should have,

$$\text{For quartz, } V^2 = 5.9536\, D_1 \times 1.64,$$
$$\text{For galena, } V^2 = 5.9536\, D_2 \times 6.586.$$

For equal-settling particles we equate the two values of V^2, and deduce

$$\frac{D_1}{D_2} = \frac{6.586}{1.64} = 4.015.$$

That is to say, the particle of quartz will have a diameter four times as large as the galena.

The minerals employed in the investigation described in this paper are given in Table I, with their specific gravity, and the multiplier which gives the diameter of the equal-settling grain of quartz, computed from Rittinger's formula for average grains.

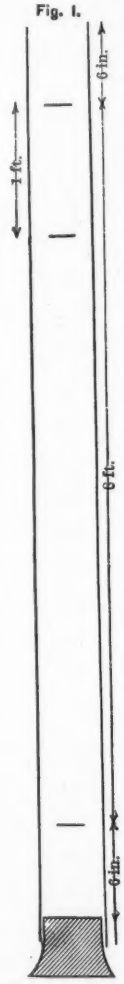
TABLE I.

Mineral.	Specific Gravity.	Multiplier for equal-settling quartz.
Anthracite	1.473	.288
Quartz	2.640	1.00
Epidote	3.380	1.45
Sphalerite	4.046	1.85
Pyrrhotite	4.508	2.14
Magnetite	4.937	2.43
Chalcocite	5.334	2.64
Arsenopyrite	5.627	2.82
Cassiterite	6.261	3.22
Antimony (artificial)	6.706	3.48
Wolframite	6.937	3.64
Galena (cubic)	7.586	4.01
Copper (Lake Superior)	8.479	4.56

Rittinger (1866) considers the law of equal-settling particles to be the law of jigging, and infers, in consequence, that a jig should be fed with particles of galena and quartz, for example, that are in no case equal-settling. To prepare the sands for a series of jigs, then, there will be required a series of sieves graded according to the diameters of their meshes. The ratio for the diameters of these meshes for jigging quartz and galena, for example, will be 1 : 4, and for the other minerals, as the multipliers given in Table I.

Upon this theory the continental system of close sizing before jigging has been developed.

Fig. 1.

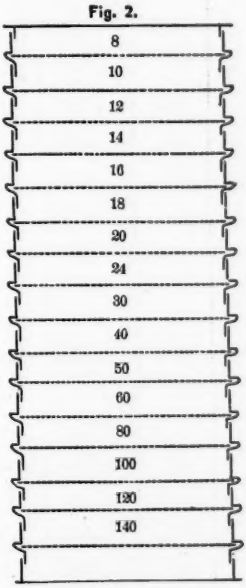


SORTING-TUBE.

With a view to studying this question experiments were instituted upon the rates of falling in water, and for this purpose a sorting-tube of the size indicated in Figure 1, and marked at *a*, *b*, and *c*, was mounted vertically and filled with water to the top. Each mineral was sized by a series of sieves, the values of the holes in which were obtained with great care.

Table II shows the manner in which the size of the grains delivered upon each sieve was computed. For convenience the sieves were arranged in a nest (see Figure 2), so that when the nest was shaken a sample of mineral placed on the upper sieve delivered

Fig. 2.



NESTS OF SIEVES.

all its different sizes, each upon its own sieve. Fall-velocities were obtained by allowing a number, perhaps fifty, of grains of the same size to fall the distance of 8 feet, from *a* to *c* in the sorting-tube, and

noting the period required for the passage of the fastest grain, and also the time required for approximately 90 per cent. of the grains to pass. This proportion of 90 per cent. was preferred to the observation of the slowest grain, because the slowest often lags an indefinite distance behind. The results of these tests are given for fastest grains in Table III; for slowest, in Table IV.

TABLE II.

COMPUTATION OF GRAIN-SIZES.

Mesh.	Meshes per inch One Way.	Diameter of Wire. (Inches.)	Net Linear Size of Hole. (Inches.)	Meshes per inch the Other Way.	Diameter of Wire. (Inches.)	Net Linear Size of Hole. (Inches.)	Av. Linear Size of Hole. (Inches.)	Av. of Size and One Above It.
3	3	.0503	.2830	3	.0503	.2830	.2830	....
4	3.75	.0471	.2196	$4\frac{1}{16}$	.0447	.1977	.2087	.2458
5	5.25	.0404	.1500	5	.0404	.1596	.1548	.1817
6	6	.0352	.1315	5.9	.0365	.1330	.1322	.1435
8	8	.0280	.0970	7.5	.0279	.1054	.1012	.1167
10 old	10	.0250	.0750	$8\frac{5}{8}$	.0250	.0909	.0830	.0921
10 new	10.4	.0250	.0712	10	.0220	.0780	.0746	.0879
12	12	.0221	.0613	11.8	,0221	.0626	.0619	.0725[1] .0683[2]
14	14	.0197	.0517	14	.0197	.0517	.0517	.0568
16	16	.0182	.0443	14.6	.0183	.0502	.0472	.0495
18	18	.0170	.0386	18.4	.0158	.0386	.0386	.0429
20	18.8	.0161	.0371	20	.0156	.0344	.0357	.0372
24	22	.0133	.0322	24	.0138	.0279	.0300	.0329
30	28	.0124	.0233	30	.0121	.0213	.0223	.0262
40	35	.0100	.0186	40	.0100	.0150	.0168	.0195
50	40	.0090	.0160	50	.0083	.0117	.0138	.0153
60	61.5	.0081	.0081	47	.0076	.0136	.0109	.0124
80	67	.0055	.0094	81	.0055	.0068	.0081	.0095
100	101	.0047	.0052	102	.0043	.0055	.0054	.0068
120	116	.0034	.0052	120	.0034	.0049	.0051	.0052
140	128	.0034	.0044	136	.0034	.0039	.0042	.0046

[1] Average of 12 with old 10-mesh. [2] Average of 12 with new 10-mesh.

TABLE III.

Fall-Tube Results. Fastest Grains.

		No. Observations.	Copper.	No. Observations.	Galena.	No. Observations.	Wolframite.	No. Observations.	Antimony.	No. Observations.	Cassiterite.	No. Observations.	Arsenopyrite.	No. Observations.	Chalcocite.	No. Observations.	Magnetite.	No. Observations.	Pyrrhotite.	No. Observations.	Sphalerite.	No. Observations.	Epidote.	No. Observations.	Quartz.	No. Observations.	Anthracite.
Specific gravity . .		..	8.479	..	7.586	..	6.937	..	6.706	..	6.261	..	5.627	..	5.334	..	4.987	..	4.508	..	4.046	..	3.380	..	2.640	..	1.473
Sieve.	Average Diameter of Grains.	.	Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.
10–12	.07246	11	17.601	20	17.085	10	16.032	15	16.180	10	16.066	10	15.421	10	13.307	20	13.427	10	13.218	6	10.472	8	10.520	20	8.746	10	3.743
12–14	.05683	10	16 410	12	16.000	10	14.970	12	14.287	12	14.558	10	13.543	10	12.149	20	12.559	10	12.075	10	9.746	6	9.365	20	7 314	10	3.194
14–16	.04947	10	15.238	20	15.186	10	14.090	10	13.226	10	13.738	12	12.962	10	11.160	17	11.412	10	10.909	10	9.121	8	8.817	20	6.579	10	3.026
16–18	.04291	10	14.091	20	14.054	10	13.175	12	12.320	10	13.018	10	12.229	10	10.830	20	10.644	10	10.247	6	8.515	10	8.348	20	6.168	3	2.704
18–20	.03716	10	12.590	20	12.862	10	11.962	10	10.955	10	11.601	10	10.621	8	9.283	12	9 375	10	8.984	10	7.773	10	7.320	20	5 597	3	2.360
20–24	.03286	10	12.467	20	12.229	10	10.785	10	10.448	10	10.831	10	10.294	10	8.706	20	8.707	10	8.291	10	7.138	10	6.724	20	5 249	3	2.194
24–30	.02615	11	11.583	20	10.855	10	9.708	10	9.388	10	9.624	10	9.197	10	7.983	20	7.983	10	7.398	6	6.261	10	6.085	20	4.596	3	1.901
30–40	.01954	11	8.892	20	8.914	10	7.986	10	7.413	8	7.641	8	7.019	10	6.529	15	6.530	10	6.358	10	5.224	10	4.989	20	3.525	3	1.631
40–50	.01530	11	7.217	20	7 314	10	6.621	10	6.503	10	6.405	10	5.872	10	5.259	20	4.764	10	5.167	10	4.133	10	4.050	20	2.879	3	1.280
50–60	.01235	10	5.818	20	6.064	10	5.549	10	5.472	10	5.533	8	4.986	10	4 579	..	.....	10	4.153	5	3.497	10	3.316	20	2.412	3	1.040
60–80	.00950	10	4.869	20	4.821	10	4.643	10	4.426	8	4.424	10	4.042	10	3.664	..	.....	10	3.337	10	2.783	10	2.731	20	2 040	3	.740
80–100	.00676	10	3.722	24	3.579	10	3.388	10	3.316	10	3.241	8	2.953	10	2.651	..	.....	10	2.441	10	2.118	10	1.955	20	1.378	3	.640
100–120	.00523	10	2.637	20	2.655	11	2.472	10	2.850	10	2.384	10	2.023	10	1.960	..	.....	8	1.912	10	1.564	10	1.453	20	0.951	2	.492
120–140	.00461	10	2.302	13	2.345	10	2.285	6	2.635	10	2.152	10	1.903	9	1.803	..	.....	10	1.744	5	1.437	10	1.348	17	0.795	1	.387[1]
140	.00416	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....

[1] Measured upon 1-foot fall, instead of 8 feet (from *a* to *b*, Figure 1).

TABLE IV.

Fall-Tube Results. Slowest Grains.

Sieve.	Average Diameter of Grains.	No. Observations.	Copper.	No. Observations.	Galena.	No. Observations.	Wolframite.	No. Observations.	Antimony.	No. Observations.	Cassiterite.	No. Observations.	Arsenopyrite.	No. Observations.	Chalcocite.	No. Observations.	Magnetite.	No. Observations.	Pyrrhotite.	No. Observations.	Sphalerite.	No. Observations.	Epidote.	No. Observations.	Quartz.	No. Observations.	Anthracite.
Specific gravity . .		..	8.479	..	7.586	..	6.937	..	6.706	..	6.261	..	5.627	..	5.334	..	4.987	..	4.508	..	4.046	..	3.380	..	2.640	..	1.473
			Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.		Velocity. Inches per Second.
10–12	.07246	11	9.163	20	12.821	10	10.548	15	9.931	10	10.727	10	9.697	10	7.868	20	9.343	10	7.681	6	7.245	8	6.294	20	4.993	10	1.383
12–14	.05683	10	8.205	12	12.063	10	9.625	12	8.289	12	8.597	10	8.292	10	6.378	20	7.893	10	6.337	10	6.465	6	5.792	20	4.311	10	1 179
14–16	.04947	11	7.427	20	11.195	10	8.256	10	8.118	10	7.649	12	7.291	10	5.800	17	7.318	10	5.880	10	5.914	8	4.986	20	4.363	10	.991
16–18	.04291	10	6 931	20	9.667	10	7.442	12	6.827	10	7.046	10	5.800	10	4.872	20	6.249	10	5.154	6	5.327	10	4.247	20	3.845	3	.842[1]
18–20	.03716	10	5.783	20	9.057	10	6.296	10	6.079	10	6.550	10	5.203	8	4.401	12	5.377	10	4.614	10	4.788	10	4.016	20	3.398	3	.818
20–24	.03286	10	5.509	20	8.153	10	5.749	10	5.333	10	5.749	10	4.201	10	4.025	20	4.706	10	4.277	10	4.103	10	3.558[1]	20	2.801	3	.750
24–30	.02615	11	4.363	20	6.579	10	4.572	10	4.433	10	4.496	10	2.962	10	3.345	20	4.000	10	3.153	6	3.064	10	1.943[1]	20	2.221	3	.560
30–40	.01954	11	3.125[1]	20	5 203	10	3.357	10	3.425	8	3.675	8	2.222	10	2.087	15	3.185	10	2.013	10	2.259	10	1.315	20	1.576	3	.413
40–50	.01530	10	2.243	20	4.000	10	2.513	10	2.596	10	3.077	5	1.655	10	1.621[1]	20	2.180	10	1.556[1]	10	1.630	10	1.057	20	1 261	3	.316
50–60	.01235	12	1.765	20	3.333	10	1.913[1]	3	1.397	10	2.167	5	1.154	10	1.299	..	.....	10	1.026	5	1.277	10	.728	20	1.026	3	.228
60–80	.00950	10	1.304	20	2 087	10	1.345	7	1.181[1]	8	1.435	3	.598	10	.749	..	.....	10	.650	5	.800	10	.390	20	.660	3	.151
80–100	.00676	10	.910	24	1.328	10	.768	10	.561	10	.....	1	.337	10	.367	..	.....	10	.405	2	.480	10	.206	10	.355	3	.082
100–120	.00523	10	.634	5	0.934	11	.532	10	.454	10	.....	1	.133	9	.245	..	.....	8	.247	1	.305	10	.155	3	.230	2	.061
120–140	.00461	10	.536	5	.828	10	.462	6	.388	10	.....	..	.....	7	.262	..	.....	1	.214	1	.291	10	.138	2	.210	1	.045
140	.00416	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....	..	.....

[1] This value, and all below it in the same column, was measured on 1-foot fall instead of 8 feet.

The specific gravities are the result of three or four closely agreeing tests. The diameters are given in fractions of an inch; the velocities, in inches per second. In all cases the grains were thoroughly wetted, and in many cases they were boiled in water before being dropped.

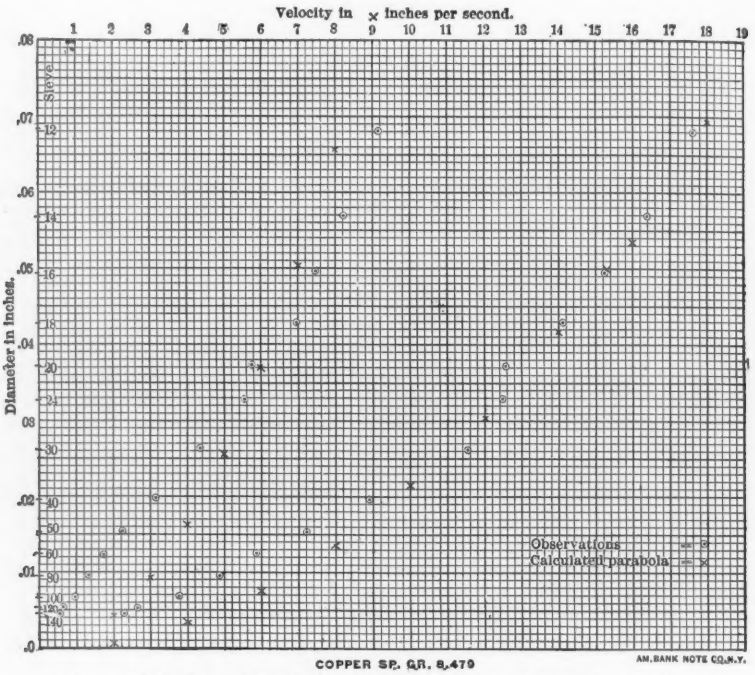
Some remarks are called for by apparent inconsistencies in Table III. In nearly every instance cassiterite fell faster than antimony, although its specific gravity is lower. I explain the low specific gravity given by the presence of a little quartz in included grains with the cassiterite, while the free grains probably have a higher specific gravity than antimony, and fall ahead of that metal, as they should. The inconsistency between chalcocite and magnetite is due to the shape of the particles; magnetite has rounded or cubical grains; chalcocite is very flat and scaly. Copper does not lead galena nearly so much as one would expect. This is due to the shape of the particles. The copper was Calumet and Hecla stamp-copper, as free as possible from rock, pieces being all more or less flattened, and the finer particles were to some extent arborescent and leaf-like, while the galena was taken from large pure cubes of Wisconsin mineral. The work upon magnetite broke down at the 60-mesh sieve, sizes below attracting each other so much that the large flakes resulting made a test impossible.

The fall-velocities for the slowest particles, that is, the particles which fell at a period when 90 per cent. (as estimated by the eye) had fallen, are given in Table IV. These are perhaps of less value than those of the fastest particles, since there is a certain personal equation which may vary. But for other reasons, as I think I shall be able to show later, these values are of very great interest and play an important part in the whole ore-dressing discussion. The values marked[1] and all below them in the columns were measured upon 1-foot fall instead of 8 feet, and are therefore somewhat better determinations than the values for the corresponding sizes in the other columns. Towards the lower ends of these columns frequent inconsistencies will be noted. They are, however, not very serious, and are accounted for partly as in the case of the fastest grains (Table III), and partly by the difficulty in judging the 90 per cent.

That the meaning of the figures in Tables III and IV may be more plainly shown to the eye, curves may be drawn representing the fastest and slowest grains for each mineral. The points of actual

observation, and those of the corresponding calculated parabola, are shown in diagrams 1 to 13 inclusive.

DIAGRAM 1.


Velocity in inches per second.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Diameter in inches.
.08 .07 .06 .05 .04 .03 .02 .01 .0
Sieve
12 14 16 18 20 24 30 40 50 60 80 100 120 140
Observations
Calculated parabola
COPPER SP. GR. 8.479
AM. BANK NOTE CO. N.Y.

Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

The parabolas that are plotted in these diagrams with the fall-velocities were calculated as follows: For example, take the fastest grains of galena. A point is selected on the .05 inch diameter line which would apparently bring the parabola well among the observed points. Its velocity, 15.2 inches per second, is read upon the upper line. We then fill in the formula for the parabola.

$$\frac{V^2}{D} = C.$$

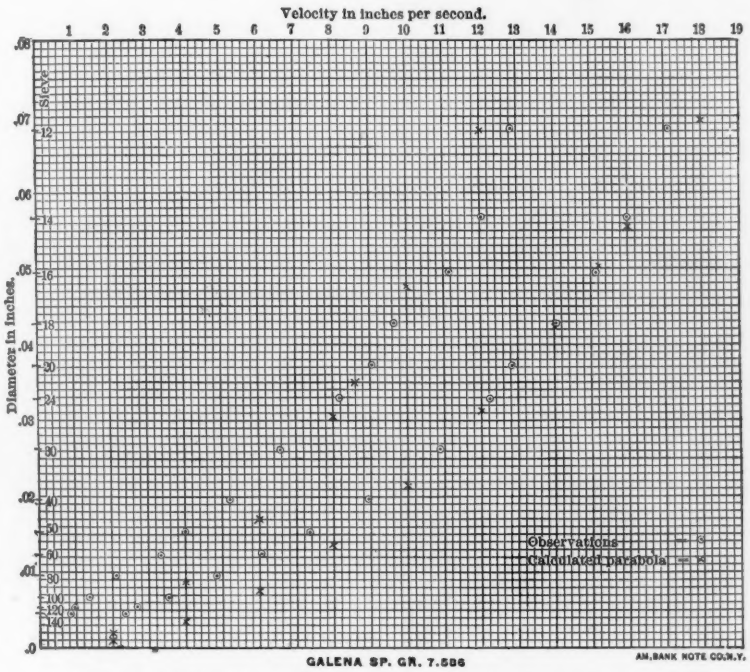
V = velocity in inches per second.

D = diameter of the grain in inches.

C = a constant.

$$\frac{15.2 \times 15.2}{.05} = C = 4621.$$

DIAGRAM 2.



Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

We then assume different velocities and solve the equation,

$$\frac{V^2}{D} = 4621,$$

to get the values of D. D and V being known, the plotting of the curve is easily done.

Table V shows, for these thirteen minerals, both Rittinger's and the author's parabolas for fastest and slowest grains.

The discrepancy between the two sets of parabolas is striking. That Rittinger's values for the slowest grains should be less than mine is natural, since I did not wait to get absolutely the last grain, but marked the moment when 90 per cent. (estimated) had passed. In regard to the fastest grains, however, my method of letting fifty grains fall at a time selects by natural process the fastest grains of the fifty,

and should yield higher results than the method of picking out compact grains by the eye, and letting them drop one at a time. The test makes a more perfect selection than can the eye. Individual grains were tried, and found to confirm this view.

TABLE V.

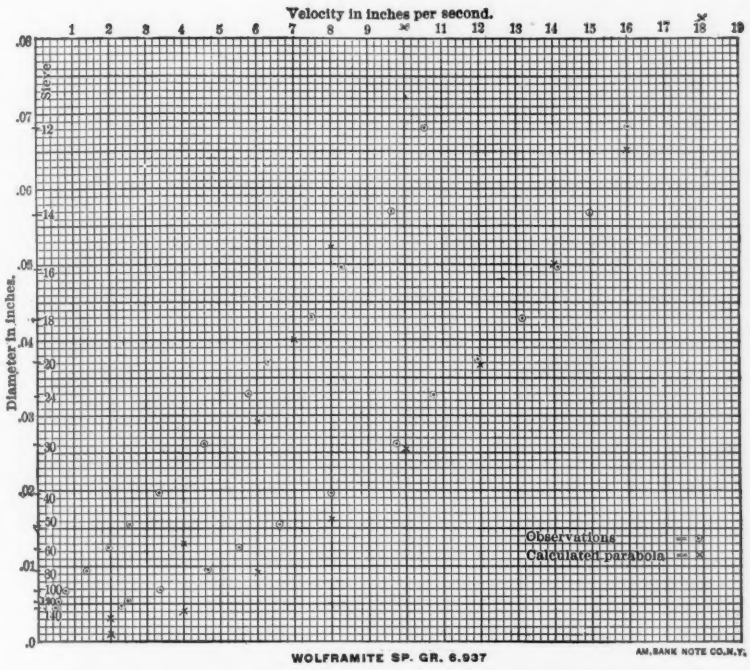
COMPUTED PARABOLAS OF FALL.

MINERAL.	Rittinger's Parabolas.		Author's Parabolas.	
	For Fastest Grains.	For Slowest Grains.	For Fastest Grains.	For Nearly the Slowest Grains.
	$\frac{V^2}{D}$	$\frac{V^2}{D}$	$\frac{V^2}{D}$	$\frac{V^2}{D}$
Copper	2229	1102	4683	973
Galena	1977	972	4621	2113
Wolframite	1769	875	3920	1225
Antimony	1701	841	3540	1056
Cassiterite	1569	776	3844	1156
Arsenopyrite	1380	682	3425	812
Chalcocite	1293	639	2599	673
Magnetite	1189	588	2599	1037
Pyrrhotite	1046	517	2520	720
Sphalerite	909	450	1730	720
Epidote	709	352	1585	520
Quartz	489	242	925	353
Anthracite	141	70	180	20

The computations made by A. E. Woodward and myself from Rittinger's formulas, and published in our paper on this subject (*Transactions of the American Institute of Mining Engineers, 18, 644*), must therefore give place to the present figures obtained by actual test.

To compare further the results obtained by the fall-tube with those of Rittinger, the ratios of diameters of the particles of the several

DIAGRAM 3.

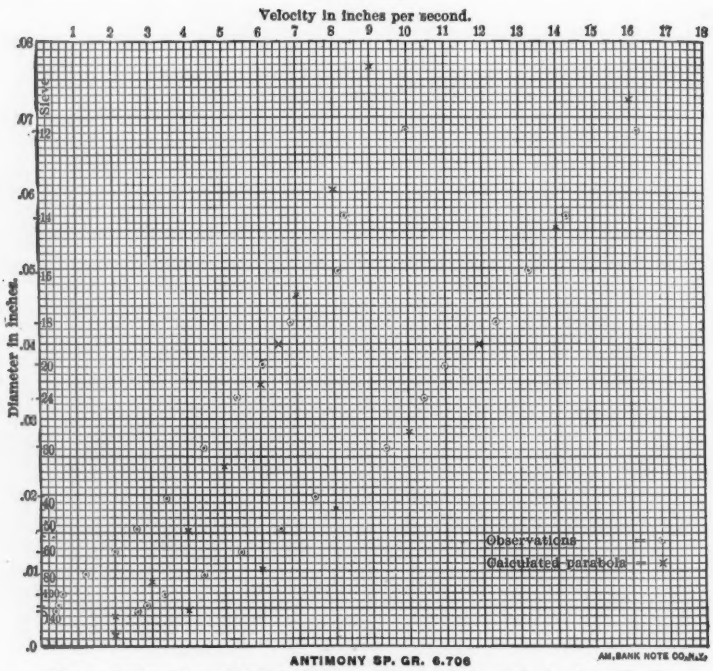


Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

minerals to those of equal-settling particles of quartz were determined as follows: A number of velocities were assumed, and corresponding diameters of the fastest grains for each mineral were taken from the curves of free-falling particles. These values are here tabulated. (See Table VI.)

From these figures for fastest grains were computed multipliers to be used in obtaining the diameters of equal-settling particles of quartz. These are given in Table VII, in the final column of which Rittinger's multipliers for average grains are also given.

DIAGRAM 4.


Velocity in inches per second.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Diameter in inches.
.08 .07 .06 .05 .04 .03 .02 .01 .0
Observations
Calculated Parabola
ANTIMONY SP. GR. 6.706
AM. BANK NOTE CO. N.Y.

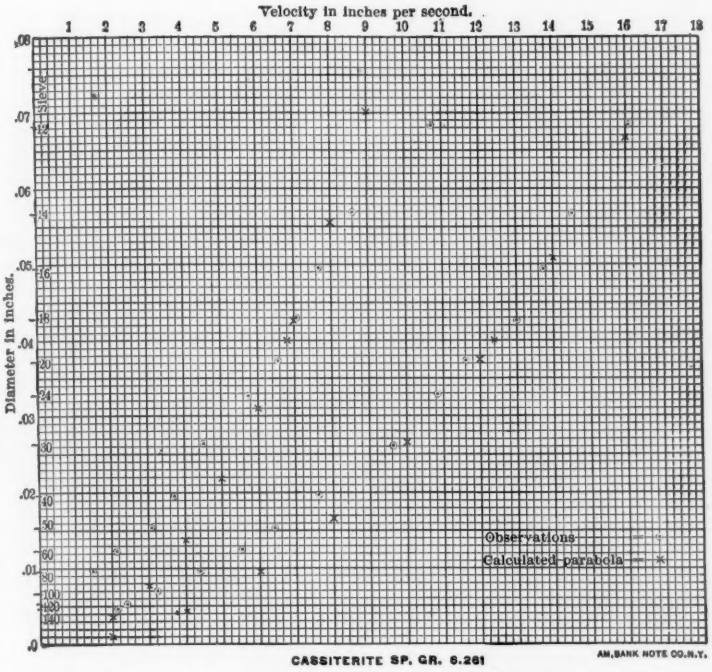
Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

TABLE VI.

DIAMETERS CORRESPONDING TO GIVEN VELOCITIES OF FALL.

MINERAL.	VELOCITY IN INCHES PER SECOND.								
	1	2	3	4	5	6	7	8	9
	Diameter in Inches.								
Anthracite	.011	.027	.049	.080	.....	.....	.....	.....	.....
Quartz	.0055	.0095	.011	.017	.03	.041	.053	.064	.075
Epidote	.0035	.007	.0105	.015	.02	.0255	.034	.041	.051
Sphalerite	.....	.0065	.0105	.0145	.0185	.025	.0315	.0385	.048
Pyrrhotite	.....	.0055	.0085	.0115	.015	.0185	.0235	.03	.036
Chalcocite	.....	.005	.0075	.0105	0145	.018	.022	.0262	.0345
Arsenopyrite	.....	.005	.007	.009	.0124	.016	.0195	.0225	.0255
Cassiterite	.....	.0045	.00615	.0085	.011	.014	.0175	.021	.024
Antimony	.....	.0035	.0055	.0085	.011	.014	.0175	.0215	.025
Wolframite	.....	.0035	.006	.0082	.0105	.0135	.0165	.0195	.023
Galena	.....	.0035	.006	.0075	.010	.012	.0145	.017	.020
Copper	.....	.0035	.0055	.0072	.010	.0128	.0148	.017	.020

DIAGRAM 5.


Velocity in inches per second.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Diameter in inches.
.08 .07 .06 .05 .04 .03 .02 .01 .0
Observations
Calculated parabola
CASSITERITE SP. GR. 6.261
AM.BANK NOTE CO.N.Y.

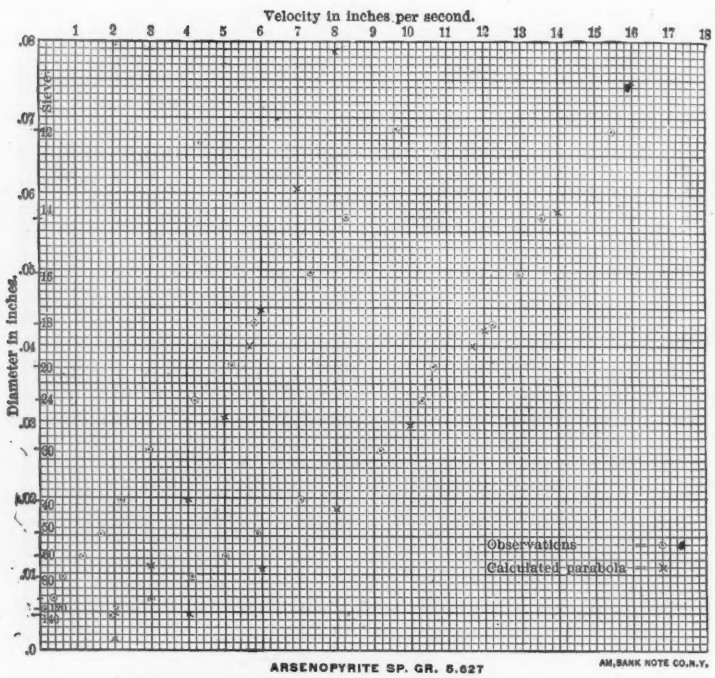
Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

TABLE VII.

EQUAL-SETTLING FACTORS, OR MULTIPLIERS FOR OBTAINING THE DIAMETER OF QUARTZ WHICH WILL BE EQUAL-SETTLING WITH THE MINERAL SPECIFIED.

MINERAL.	VELOCITY IN INCHES PER SECOND.									Rittinger's Multipliers.
	1	2	3	4	5	6	7	8	9	
	Author's Multipliers.									
Anthracite	.500	.352	.225	.213	.....	.....	.....	.....	.....	.288
Epidote	1.57	1.35	1.05	1.13	1.50	1.61	1.56	1.56	1.47	1.45
Sphalerite	.....	1.46	1.05	1.17	1.62	1.64	1.68	1.66	1.56	1.85
Pyrrhotite	.....	1.73	1.29	1.48	2.00	2.22	2.26	2.13	2.08	2.14
Chalcocite	.....	1.90	1.47	1.62	2.07	2.28	2.41	2.44	2.17	2.64
Arsenopyrite	.....	1.90	1.57	1.89	2.42	2.56	2.72	2.84	2.94	2.82
Cassiterite	.....	2.11	1.79	2.00	2.73	2.93	3.03	3.05	3.12	3.32
Antimony	.....	2.71	2.00	2.00	2.73	2.93	3.03	2.98	3.00	3.48
Wolframite	.....	2.71	1.83	2.07	2.86	3.04	3.21	3.28	3.26	3.64
Galena	.....	2.71	1.83	2.26	3.00	3.42	3.65	3.76	3.75	4.01
Copper	.....	2.71	2.00	2.36	3.00	3.20	3.58	3.76	3.75	4.56

DIAGRAM 6.



Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

Upon inspection of the curves for free-falling grains, in diagrams 1 to 13, three facts are noticed:

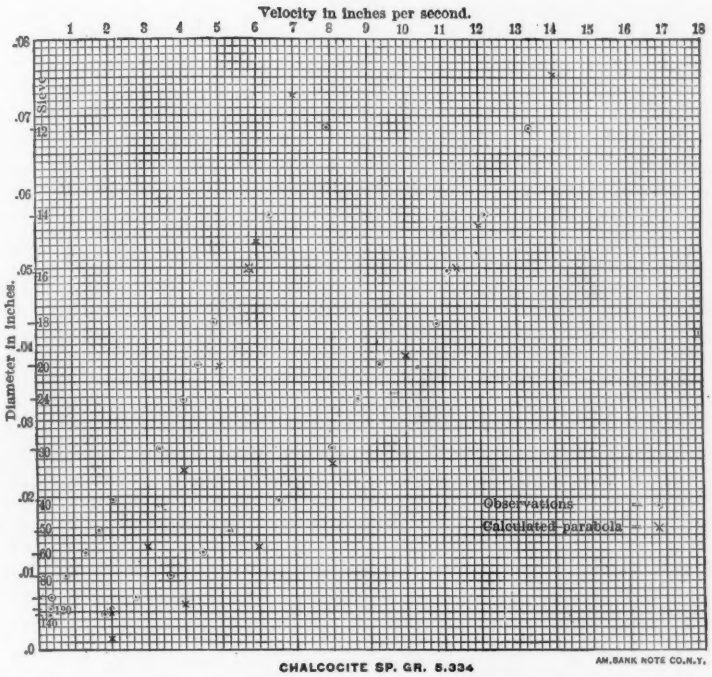
1. The lines of fastest grains and of slowest grains depart very considerably from the parabola, particularly on the smaller sizes.

2. The space between the two lines of fastest grains and slowest grains is a wide zone or belt.

3. The width of the zone may vary greatly, depending upon the shape of the particles — for example, the copper zone is much wider than that of the galena.

With regard to the first point, Rittinger makes note of the fact that his formulas fail for finer sizes. These curves, therefore, place on record the degree to which they have failed with the minerals here tested. We see that the velocity of any mineral which tends to break

DIAGRAM 7.



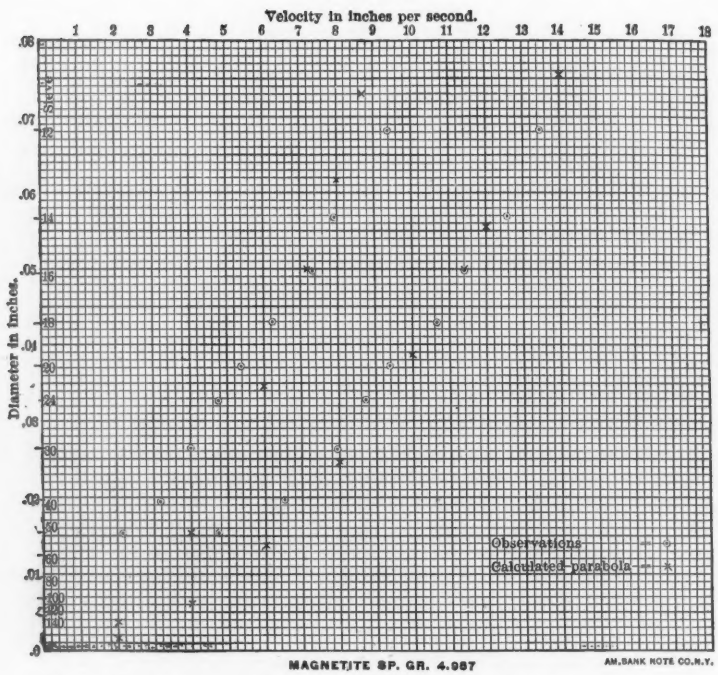
Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

into flat scales, or elongated grains (for instance, copper or chalcocite), is so modified as to change its class entirely. Thus, the curves for fastest grains of galena and copper are almost identical, although their specific gravities are widely different.

Each mineral has, therefore, its own "personal equation," and minerals cannot be classed by specific gravity alone. Hence, no formula can be founded on specific gravity and sieve size only. It must be modified by the coefficient of each mineral for practical use.

The second point, also, was recognized by Rittinger, as is shown in his formulas for fastest grains and slowest grains already quoted in this paper. But the deduction which followed from adopting a mean value for these grains has been somewhat of a puzzle to me.

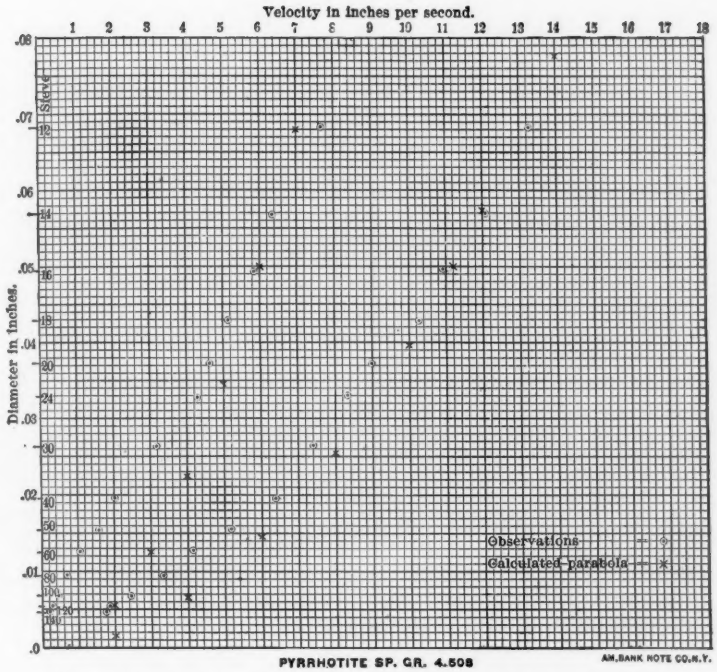
DIAGRAM 8.



Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

Let us take an example from the curves of sphalerite (blende) and quartz. A mean grain of quartz of .07 inch diameter will fall 6.7 inches in one second. Following down the sphalerite curve we find that a mean grain of sphalerite of .039 inch diameter settles 6.7 inches in one second. If, then, we were to use these mean values, as Rittinger recommends, for obtaining our sieve-scale, we should conclude that with two sieves, one having holes of .07 inch diameter and the other of .039 inch diameter, the fastest grain of quartz between these two sizes has less speed in settling than the slowest grain of the sphalerite, and therefore this product would be jiggable according to the law of equal-settling particles. But, in fact, the fastest grain of quartz falls about 8.5 inches in one second, while the slowest grain of sphalerite settles only 5 inches in one second; hence, the product

DIAGRAM 9.



Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

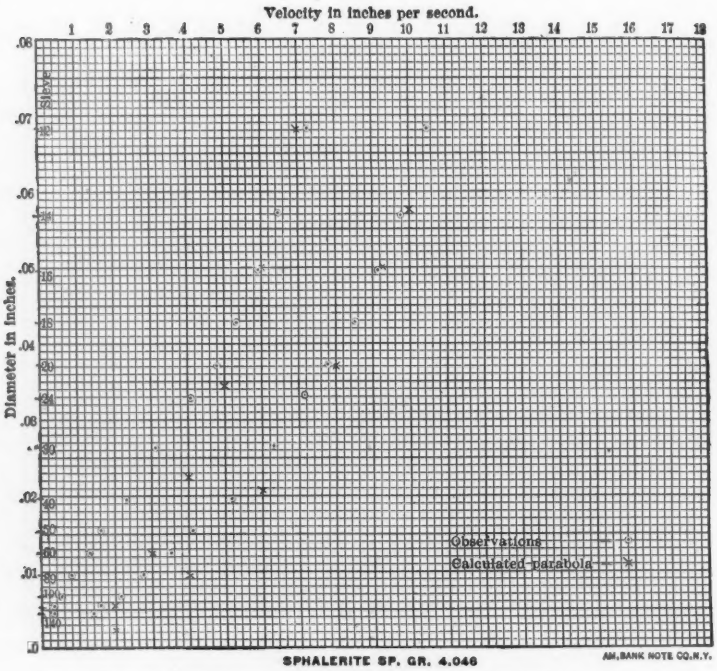
is unjiggable according to the law of equal-settling particles. Indeed, these zones of quartz and sphalerite lap over on each other even on a single sieve; and if the law of equal-settling particles were the only law of jigging, sphalerite and quartz could not be sized closely enough to prepare them for jigging.

The converse seems, therefore, evident; namely, that under no circumstances is the law of equal-settling particles the whole law of jigging.

II. INTERSTITIAL CURRENTS.

Professor H. S. Munroe tested in 1889 the effect of confined space upon falling particles. He timed different sizes of lead shot or spheres falling in a narrow glass tube filled with water (Figure 3a).

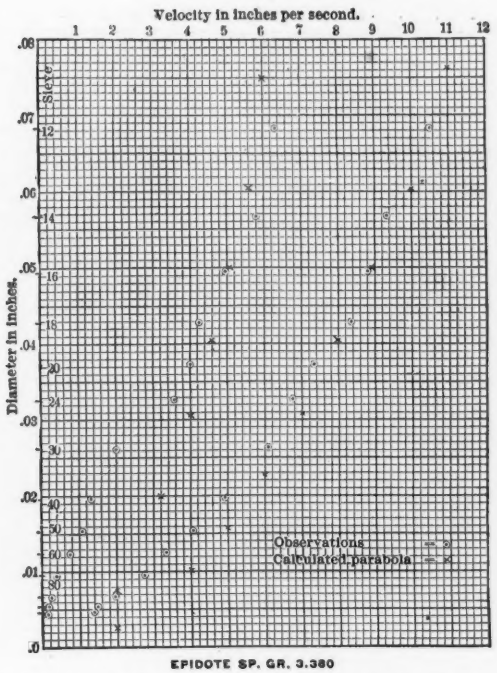
DIAGRAM 10.


Velocity in inches per second.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Diameter in inches.
.08 .07 .06 .05 .04 .03 .02 .01 .0
Slope
Observations
Calculated parabola
SPHALERITE SP. GR. 4.046
AM. BANK NOTE CO. N.Y.

Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

If d equals the diameter of the shot and D that of the tube, he found that the larger the fraction $\frac{d}{D}$ the greater was the retardation or loss of velocity by the shot. When this fraction equals unity the shot stops. He applies this principle to the question of equal-settling particles as follows: If particles of quartz, for example (Figure 3b), are represented by the larger circles, and those of equal-settling galena by the smaller circles, then when these mixed particles are settling *en masse*, or are held in suspension by a rising current of water, each particle may be considered to be falling in a tube, the walls of which consist of the surrounding particles. Substituting a circle in each case for the imaginary tube, we have

DIAGRAM 11.



Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

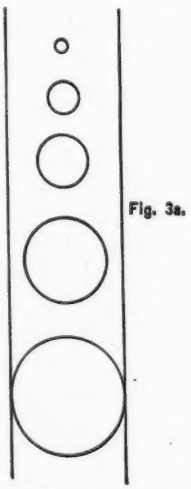
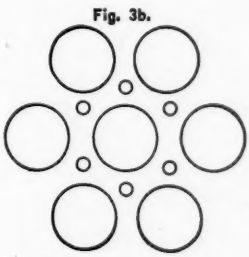


Fig. 3a.

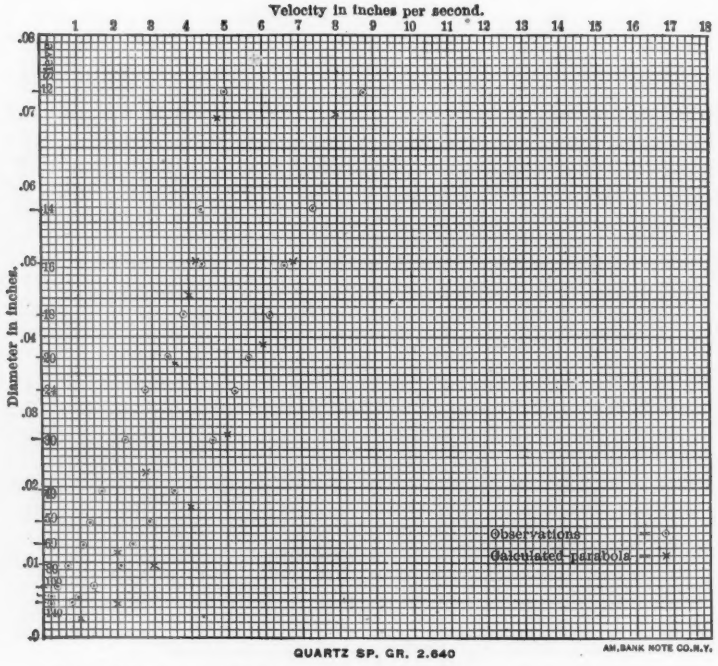
FALLING SPHERES.

Fig. 3b.



INTERSTITIAL FALL.

DIAGRAM 12.



Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

Figure 4, representing the conditions for galena and quartz, the outer circle representing in each case the imaginary tube. A glance is sufficient to show us that the fraction $\frac{d}{D}$ is much smaller for the galena particle than it is for the quartz. The galena particle will, therefore, be less impeded in its fall than the quartz, and in consequence the particles of galena that are found adjacent to the particles of quartz will be smaller than the ratio which the law of equal-settling particles would indicate. Professor Munroe infers that these interstitial currents account for the fact, made use of in the mills, that a jig will save galena which is much finer than would be the case if the law of equal-settling particles was the only law of jigging.

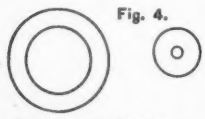
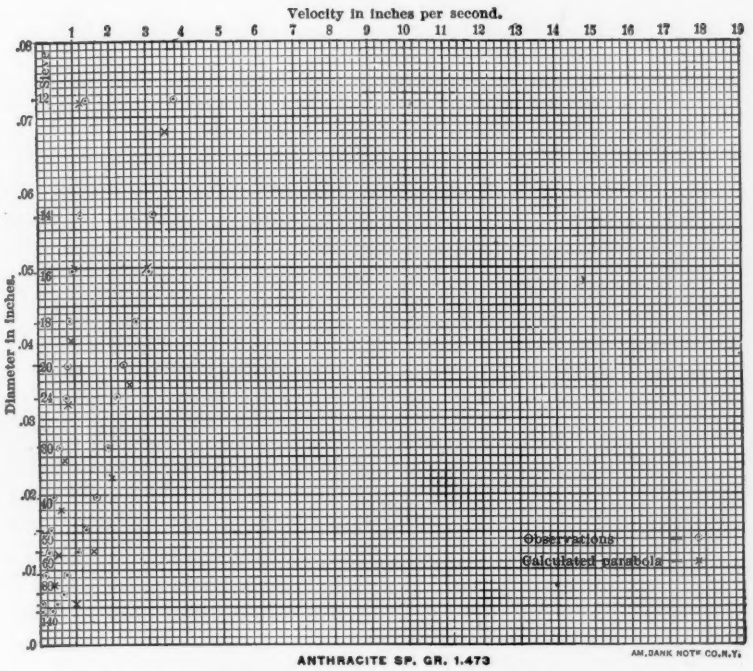


Fig. 4.

IMAGINARY TUBES OF INTERSTITIAL FALL.

DIAGRAM 13.

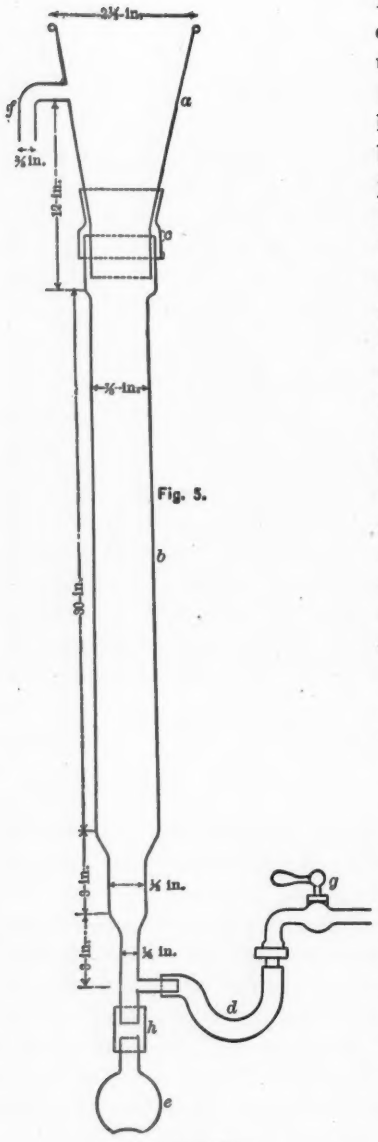


Observed Velocities of Fall in Water, with Parabolas Calculated to Conform Most Nearly Thereto.

And he finally proves, by equating his formulas, that the ratio of diameters for the quartz and galena after the interstitial currents have brought the grains to equilibrium will be as 30 : 1.

Professor Munroe says further (*Trans.* 17, 650): "We see, therefore, that if the material to be treated is sized between the limits of 1 mm. and 30 mm., it will be possible to separate the quartz from the galena. All the spheres of galena will have a greater falling velocity than the 1 mm. grain; all the quartz will rise more readily and fall more slowly than the 30 mm. grain."

I have recently attempted to ascertain by experiment to what extent this law of interstitial currents acts upon irregular particles. For this purpose I constructed a pointed tube of the form shown in



POINTED TUBE.

Figure 5, which consists of a tin cone (*a*), with an overflow (*f*), united to a pointed tube of glass (*b*) by a rubber connector (*c*), and having a water supply (*d*) regulated by the cock (*g*), and a bulb (*e*) joined by a rubber connector (*h*). If this apparatus be filled with water, and a sample of mixed sands, which pass through a 10-mesh sieve (an ordinary 8-ounce bottleful represents the quantity used), be charged gradually at the top, and a slight upward current of water be admitted through the tube (*d*), the sands will rapidly assume a condition of approximate equilibrium. Here we have sands, say, of two specific gravities and of sizes, ranging from 10-mesh to dust, which are held in gently moving suspension by the slow upward current. This device presents, therefore, the conditions necessary to test the limits of interstitial currents.

By means of this pointed tube the behavior of the minerals named in Table VIII, taken by pairs, has been tested.

Each of these pairs was treated in the pointed tube (Figure 5) by allowing from one half hour to two hours for the grains to come to equilibrium, and since the larger part of the sorting is done in the first minute we may consider that the work is practically completed in half an hour.

TABLE VIII.

LIST OF MINERAL PAIRS TREATED IN THE POINTED TUBE.

Quartz,	specific gravity 2.640 and Copper,	specific gravity 8.479
Quartz,	specific gravity 2.640 and Galena,	specific gravity 7.586
Quartz,	specific gravity 2.640 and Wolframite,	specific gravity 6.937
Quartz,	specific gravity 2.640 and Antimony,	specific gravity 6.706
Quartz,	specific gravity 2.640 and Cassiterite,	specific gravity 6.261
Quartz,	specific gravity 2.640 and Arsenopyrite,	specific gravity 5.627
Quartz,	specific gravity 2.640 and Chalcocite,	specific gravity 5.334
Quartz,	specific gravity 2.640 and Magnetite,	specific gravity 4.987
Quartz,	specific gravity 2.640 and Pyrrhotite,	specific gravity 4.508
Quartz,	specific gravity 2.640 and Sphalerite,	specific gravity 4.046
Quartz,	specific gravity 2.640 and Epidote,	specific gravity 3.380
Quartz,	specific gravity 2.640 and Anthracite,	specific gravity 1.473

While the sands are still kept in gently moving suspension the current is slightly slackened by means of the cock (*g*), and the heavier grains are allowed to find their way down into the bulb (*e*). When the bulb is full the rubber connector (*h*) is pinched with the thumb and finger, and the bulb is replaced with a new one which has been completely filled with water, care having been taken to remove the bubble of air from the neck. In like manner the second bulb is filled and removed, and a third, a fourth, and so on until all the sand, to the finest slimes, has been drawn off. The overflow will be found to contain very light particles, and also a few particles carried over by greasy flotation. This should be caught, and may be called the last bulb or drawing.

Each of these drawings, which were ten in number, was carefully dried and then sized in the nest of sieves (Figure 2). The sizes, for example, in the galena series (see Plate II*a*) in the fifth flask were found to be perfectly pure quartz down to the 30-mesh sieve. The 40-mesh contained a little galena; the 50-mesh was nearly all galena, with a little quartz; and all the sizes below fifty were pure galena.

The twelve pairs of minerals were all treated in this way, and the photographs (Plates I to XII inclusive) show the results obtained in the form of a graphical plot of the actual grains. The vertical columns Nos. 1, 2, 3, 4, etc., represent the successive bulbs. The horizontal lines indicate groups of particles resting upon like sieves.

This series of photographs shows very prettily what can be done

with a pointed tube in the way of water sorting preparatory to sizing. A series of tables (Tables IX to XXI inclusive) has been prepared to accompany the photographs. These tables, giving the estimated percentage in every hill of the mineral which was to be concentrated, will be found convenient in interpreting the photographs.

In the galena-quartz photograph (Plates II*a*, II*b*) there are scarcely any mixed grains until slimes are reached. The ninth and tenth drawings are much mixed, and always will be so, coming from the apparatus here described. Their separation will be the subject of another paper.

The same is true of the copper-quartz photograph (Plate I) except that the sample contained none of the very finest slimes, and therefore the ninth and tenth drawings are practically pure quartz.

Following through the various minerals and gravities we see a general set of features possessed in common, but changing a little with each successive photograph. First, we have in copper a range of clean, pure quartz hills from No. 4 on 12 to No. 9 on 100. We also have a clean range of copper hills from No. 1 on 12 to No. 8 slimes, and between the two a valley almost destitute of grains, which is widest from No. 4 on 20 to No. 5 on 30, and narrows very much at No. 8 on 120.

In arsenopyrite (Plate VI) the valley is gone on the 100-mesh line, and we have a plateau instead. In chalcocite (Plate VII) the plateau has reached up to the 50-mesh line. In pyrrhotite (Plate IX) it has reached the 40-mesh line. In epidote (Plate XI) the plateau has disappeared below 24-mesh and a single wide range of hills has taken its place.

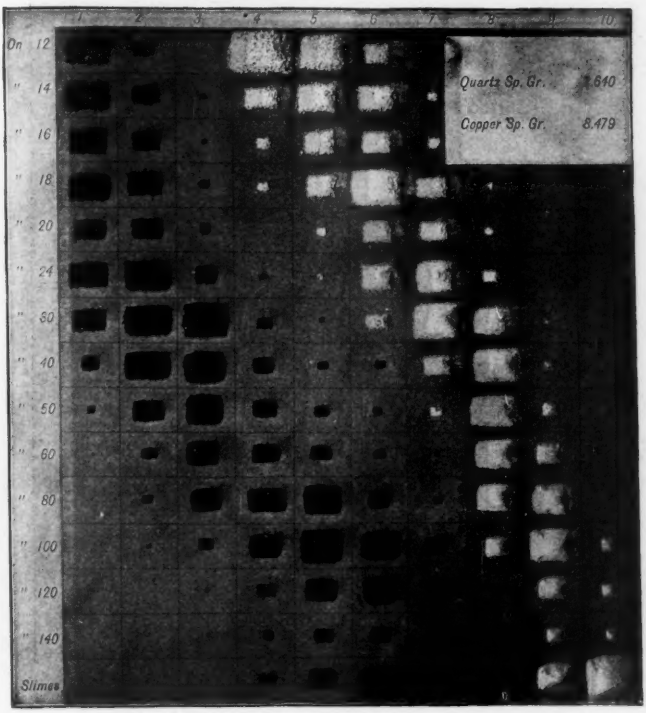
The above features are due to the convergence towards the hill marked No. 10 slimes of the two approximately parabolic curves.

A single plate (Plate XIII) is given to illustrate a three-mineral separation, in which slate (specific gravity, 2.735), barite (specific gravity, 4.127), and galena (specific gravity, 7.586) are the three minerals. Table XXII accompanies it, giving estimated percentages in the hills.

The weights of the hills for three columns of each of Plates I to XII inclusive (except VIII) will be found in the following tables—XXV to XXXVI.

They are absolute weights in every case except where a hill contained a mixture of two minerals. In such a case the total weight was

PLATE I.



Separation of Quartz and Copper by Pointed Tube and Sieves.

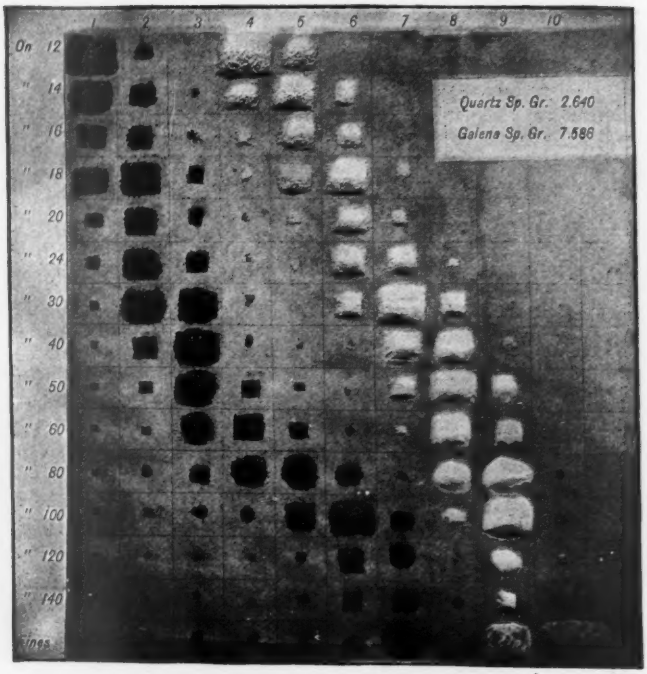
TABLE IX.

ESTIMATED PERCENTAGE OF COPPER IN THE HILLS OF PLATE I.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	.....	.....	.....	.....	.....	.....	.....	.....
14	100	100	100	.....	.....	.....	.....	.....	.....	.....
16	100	100	100	.....	.....	.....	.....	.....	.....	.....
18	100	100	100	.....	.....	.....	.....	.....	.....	.....
20	100	100	100	.....	.....	.....	.....	.....	.....	.....
24	100	100	100	100	2	.....	.....	.....	.....	.....
30	100	100	100	100	97	10	....	.....	2	.....
40	100	100	100	100	100	95	1	.....	2	20
50	100	100	100	100	100	99	7	.....	2	20
60	100	100	100	100	100	100	45	.....	2	20
80	100	100	100	100	100	100	95	.....	2	20
100	100	100	100	100	100	100	99	5	2	10
120	100	100	100	100	100	100	100	60	2	10
140	100	100	100	100	100	100	100	90	5	10
Slimes	100	100	100	100	100	100	100	99	35	5

For the weights of the hills in columns 5, 6, and 7, see Table XXV.

PLATE II*a*.



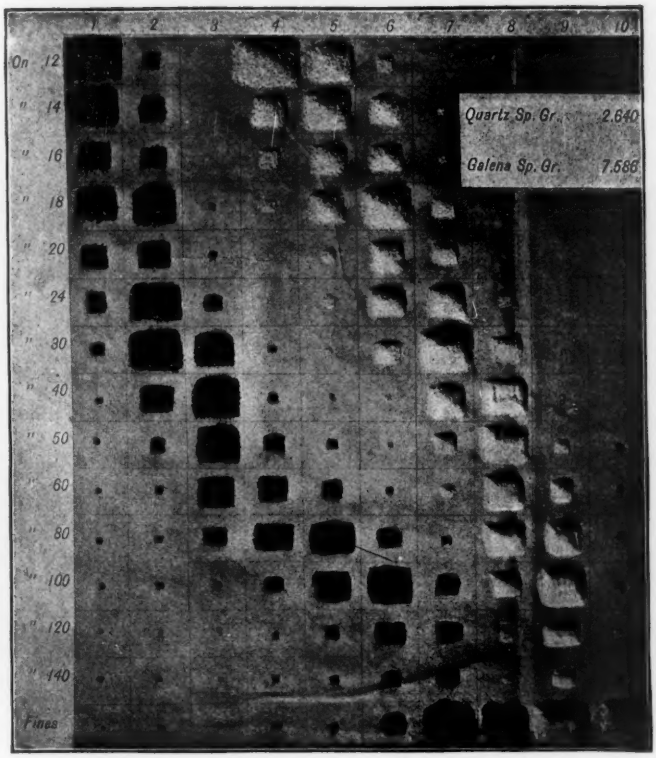
Separation (First Time) of Quartz and Galena by Pointed Tube and Sieves.

TABLE X.

ESTIMATED PERCENTAGE OF GALENA IN THE HILLS OF PLATE II*a*.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	.....	.....	.....	.....	.....	.....	.....	.....
14	100	100	100	.....	.....	.....	.....	.....	.....	.....
16	100	100	100	.....	.....	.....	.....	.....	.....	.....
18	100	100	100	.....	.....	.....	.....	.....	.....	.....
20	100	100	100	40	.....	.....	.....	.....	.....	.....
24	100	100	100	50	.....	.....	.....	.....	.....	.....
30	100	100	100	75	10	.....	.....	.....	.....	.....
40	100	100	100	90	50	10	.....	.....	.....	.....
50	100	100	100	100	90	60	.....	.....	.....	.....
60	100	100	100	100	100	90	5	.....	.....	.....
80	100	100	100	100	100	100	90	.....	.....	60
100	100	100	100	100	100	100	100	.....	.....	60
120	100	100	100	100	100	100	100	50	.....	50
140	100	100	100	100	100	100	100	90	25	50
Slimes	100	100	100	100	100	100	100	100	60	75

PLATE II*b*.



Separation (Second Time) of Quartz and Galena by Pointed Tube and Sieves.

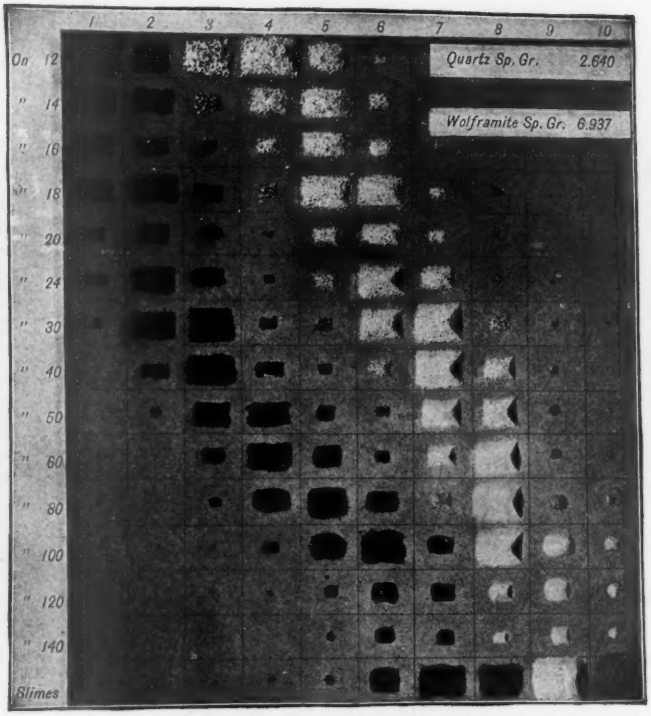
TABLE XI.

ESTIMATED PERCENTAGE OF GALENA IN THE HILLS OF PLATE II*b*.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	.....	.....	.....	.....	.....	.....	.....	.....
14	100	100	.....	.....	.....	.....	.....	.....	.....	.....
16	100	100	.....	.....	.....	.....	.....	.....	.....	.....
18	100	100	100	.....	.....	.....	.....	.....	.....	.....
20	100	100	100	.....	.....	.....	.....	.....	.....	.....
24	100	100	100	25	.....	.....	.....	.....	.....	.....
30	100	100	100	75	.....	.....	.....	.....	.....	.....
40	100	100	100	100	50	.....	.....	.....	.....	.....
50	100	100	100	100	100	50	.....	.....	.....	75
60	100	100	100	100	100	100	.....	.....	.....	75
80	100	100	100	100	100	100	40	.....	.....	75
100	100	100	100	100	100	100	90	.....	.....	50
120	100	100	100	100	100	100	100	30	.....	50
140	100	100	100	100	100	100	100	40	.....	60
Slimes	100	100	100	100	100	100	100	95	60	75

For the weights of the hills in columns 5, 6, and 7, see Table XXVI.

PLATE III.



Separation of Quartz and Wolframite by Pointed Tube and Sieves.

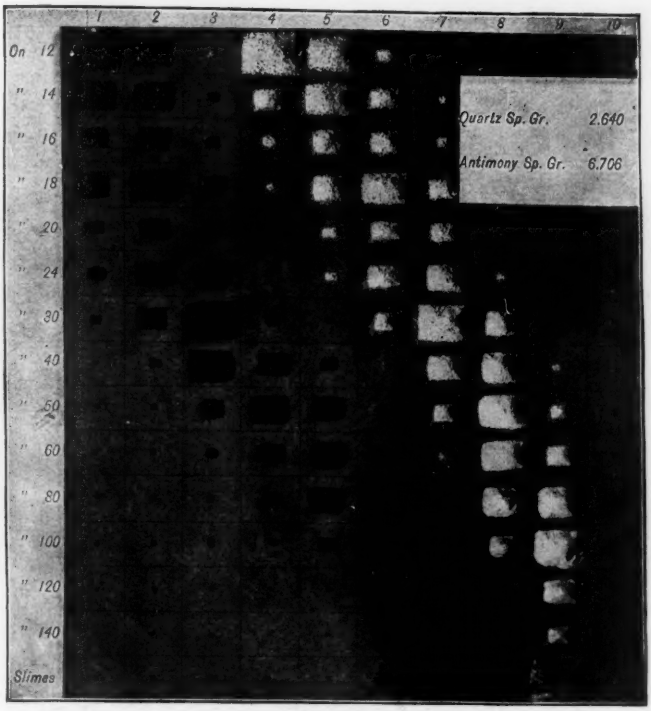
TABLE XII.

ESTIMATED PERCENTAGE OF WOLFRAMITE IN THE HILLS OF PLATE III.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	1	.....	.....	.....	.....	.....	.....	.....
14	100	100	5	.....	.....	.....	.....	.....	.....	.....
16	100	100	30	.....	.....	.....	.....	.....	.....	.....
18	100	100	75	.....	.....	.....	.....	.....	.....	.....
20	100	100	95	5	.....	.....	.....	.....	.....	.....
24	100	100	100	15	.....	.....	.....	.....	.....	.....
30	100	100	100	80	10	.....	.....	.....	.....	.....
40	100	100	100	95	85	5	.....	.....	.....	.....
50	100	100	100	100	95	20	.....	.....	.....	.....
60	100	100	100	100	100	90	1	.....	.....	.....
80	100	100	100	100	100	95	10	.....	.....	2
100	100	100	100	100	100	100	95	1	.....	2
120	100	100	100	100	100	100	100	5	.....	2
140	100	100	100	100	100	100	100	10	.....	2
Slimes	100	100	100	100	100	100	100	90	30	45

For the weights of the hills in columns 5, 6, and 7, see Table XXVIII.

PLATE IV.



Separation of Quartz and Antimony by Pointed Tube and Sieves.

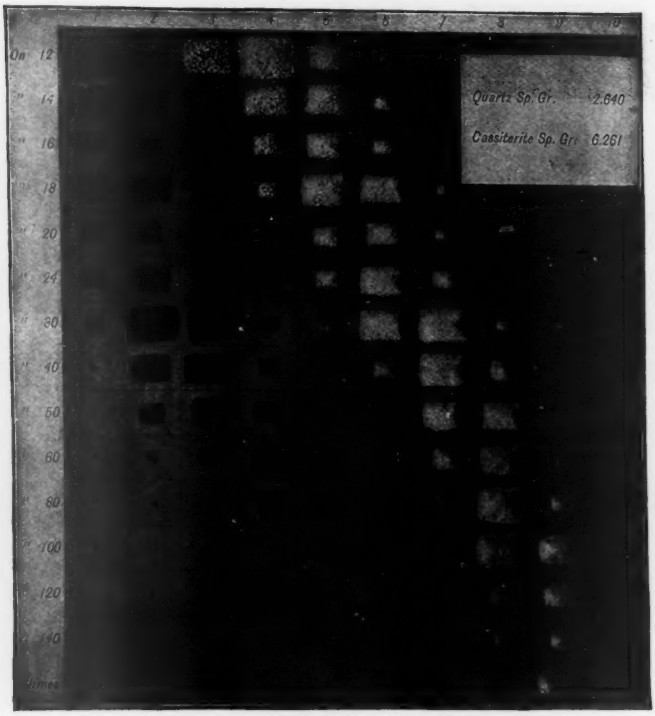
TABLE XIII.

ESTIMATED PERCENTAGE OF ANTIMONY IN THE HILLS OF PLATE IV.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	50	.....	.....	.....	.....	.....	.....	.....
14	100	100	99	.....	.....	.....	.....	.....	.....	.....
16	100	100	100	.....	.....	.....	.....	.....	.....	.....
18	100	100	100	.....	.....	.....	.....	.....	.....	.....
20	100	100	100	.....	.....	.....	.....	.....	.....	.....
24	100	100	100	95	.....	.....	.....	.....	.....	.....
30	100	100	100	100	50	.....	.....	.....	.....	50
40	100	100	100	100	100	50	.....	.....	.....	50
50	100	100	100	100	100	95	.....	.....	.....	75
60	100	100	100	100	100	100	40	.....	.....	75
80	100	100	100	100	100	100	90	.....	.....	75
100	100	100	100	100	100	100	100	30	.....	75
120	100	100	100	100	100	100	100	55	.....	75
140	100	100	100	100	100	100	100	90	.....	75
Slimes	100	100	100	100	100	100	100	100	60	80

For the weights of the hills in columns 5, 6, and 7, see Table XXIX.

PLATE V.



Separation of Quartz and Cassiterite by Pointed Tube and Sieves.

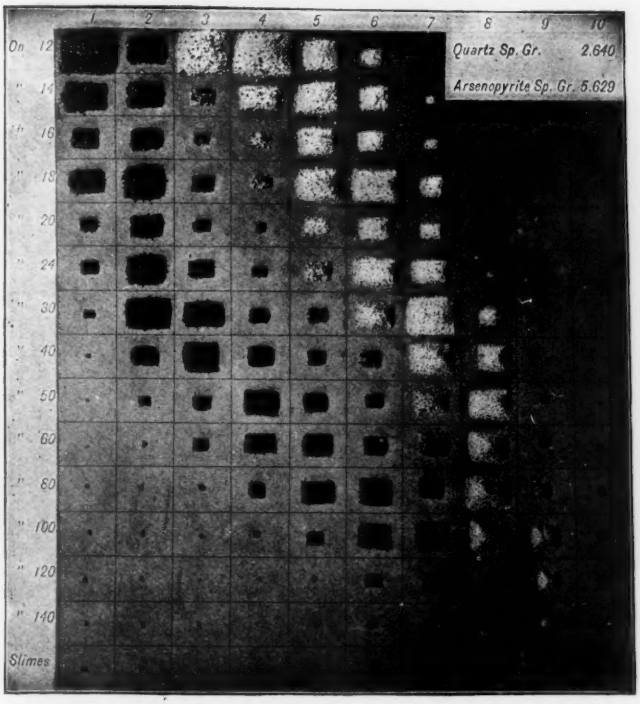
TABLE XIV.

ESTIMATED PERCENTAGE OF CASSITERITE IN THE HILLS OF PLATE V.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	10	2	.....	.....	.....	.....	.....	.....
14	100	100	75	4	.....	.....	.....	.....	.....	.....
16	100	100	95	6	.....	.....	.....	.....	.....	.....
18	100	100	100	10	.....	.....	.....	.....	.....	.....
20	100	100	100	50	.....	.....	.....	.....	.....	.....
24	100	100	100	90	2	.....	.....	.....	.....	.....
30	100	100	100	100	40	.....	.....	.....	.....	50
40	100	100	100	100	97	5	.....	.....	.....	50
50	100	100	100	100	100	40	.....	.....	2	50
60	100	100	100	100	100	90	4	.....	2	50
80	100	100	100	100	100	100	30	.....	2	50
100	100	100	100	100	100	100	80	30	2	50
120	100	100	100	100	100	100	100	40	2	50
140	100	100	100	100	100	100	100	50	2	50
Slimes	100	100	100	100	100	100	100	75	40	75

For the weights of the hills in columns 5, 6, and 7, see Table XXX.

PLATE VI.



Separation of Quartz and Arsenopyrite by Pointed Tube and Sieves.

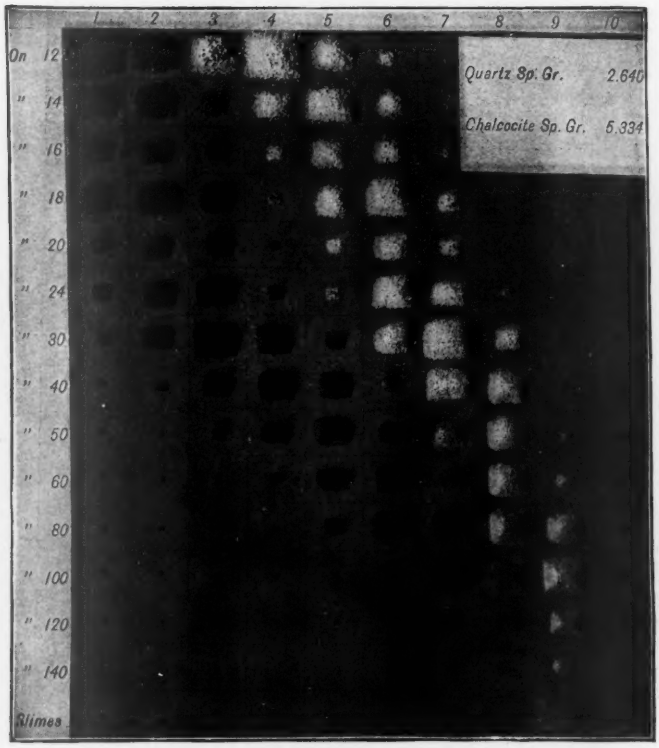
TABLE XV.

ESTIMATED PERCENTAGE OF ARSENOPYRITE IN THE HILLS OF PLATE VI.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	5	.....	.....	.....	.....	.....	.....	.....
14	100	100	40	.....	.....	.....	.....	.....	.....	.....
16	100	100	95	5	2	.....	.....	.....	.....	.....
18	100	100	99	15	4	1	.....	.....	.....	.....
20	100	100	100	90	6	1	.....	.....	.....	.....
24	100	100	100	99	15	2	1	.....	.....	.....
30	100	100	100	100	80	10	2	1	.....	.....
40	100	100	100	100	98	70	10	1	25	.....
50	100	100	100	100	100	95	25	2	50	50
60	100	100	100	100	100	100	45	5	25	50
80	100	100	100	100	100	100	80	10	15	75
100	100	100	100	100	100	100	100	15	15	75
120	100	100	100	100	100	100	100	30	15	60
140	100	100	100	100	100	100	100	50	20	50
Slimes	100	100	100	100	100	100	100	90	50	50

For the weights of the hills in columns 5, 6, and 7, see Table XXXI.

PLATE VII.



Separation of Quartz and Chalcocite by Pointed Tube and Sieves.

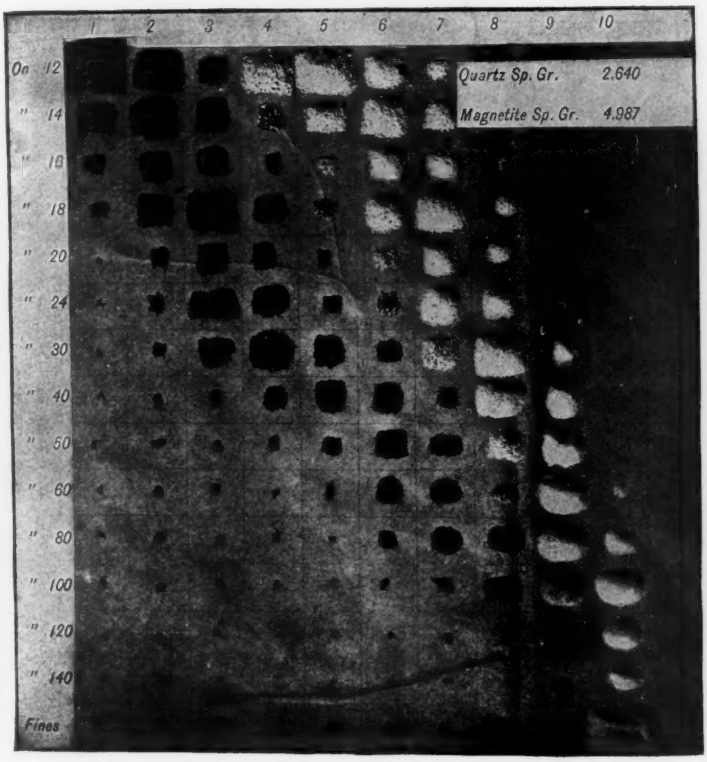
TABLE XVI.

ESTIMATED PERCENTAGE OF CHALCOCITE IN THE HILLS OF PLATE VII.

SIEVE-MESH.	1	2	3	4		6	7	8	9	10
12	100	100	10	.....	.....	.....	33	.....	.....	.....
14	100	100	90	.....	.....	.....	20	.....	.....	.....
16	100	100	100	2	.....	1	5	.....	.....	.....
18	100	100	100	50	.....	1	5	.....	.....	.....
20	100	100	100	100	1	1	5	50	.....	.....
24	100	100	100	100	35	1	5	30	....	.....
30	100	100	100	100	95	20	15	2	90	100
40	100	100	100	100	100	60	50	2	30	99
50	100	100	100	100	100	99	75	2	5	99
60	100	100	100	100	100	100	95	2	5	99
80	100	100	100	100	100	100	100	30	5	90
100	100	100	100	100	100	100	100	50	5	85
120	100	100	100	100	100	100	100	95	10	80
140	100	100	100	100	100	100	100	100	15	80
Slimes	100	100	100	100	100	100	100	100	40	75

For the weights of the hills in columns 5, 6, and 7, see Table XXXII.

PLATE VIII.



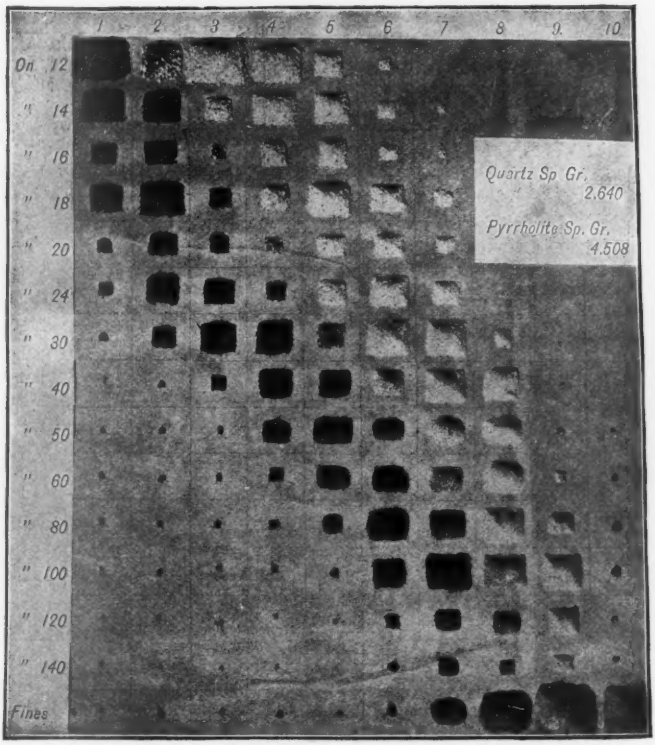
Separation of Quartz and Magnetite by Pointed Tube and Sieves.

TABLE XVII.

ESTIMATED PERCENTAGE OF MAGNETITE IN THE HILLS OF PLATE VIII.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	100	15	.....	.....	.....	.....	.....	.....
14	100	100	100	80	2	.....	.....	.....	.....	.....
16	100	100	100	100	40	.....	.....	.....	.....	.....
18	100	100	100	100	75	5	.....	.....	.....	.....
20	100	100	100	100	100	40	.....	.....	.....	.....
24	100	100	100	100	100	70	2	.....	.....	.....
30	100	100	100	100	100	100	50	.....	.....	.....
40	100	100	100	100	100	100	90	5	.....	60
50	100	100	100	100	100	100	100	35	.....	50
60	100	100	100	100	100	100	100	50	.....	15
80	100	100	100	100	100	100	100	100	10	.....
100	100	100	100	100	100	100	100	100	50	.....
120	100	100	100	100	100	100	100	100	90	.....
140	100	100	100	100	100	100	100	100	100	5
Slimes	100	100	100	100	100	100	100	100	100	35

PLATE IX.



Separation of Quartz and Pyrrhotite by Pointed Tube and Sieves.

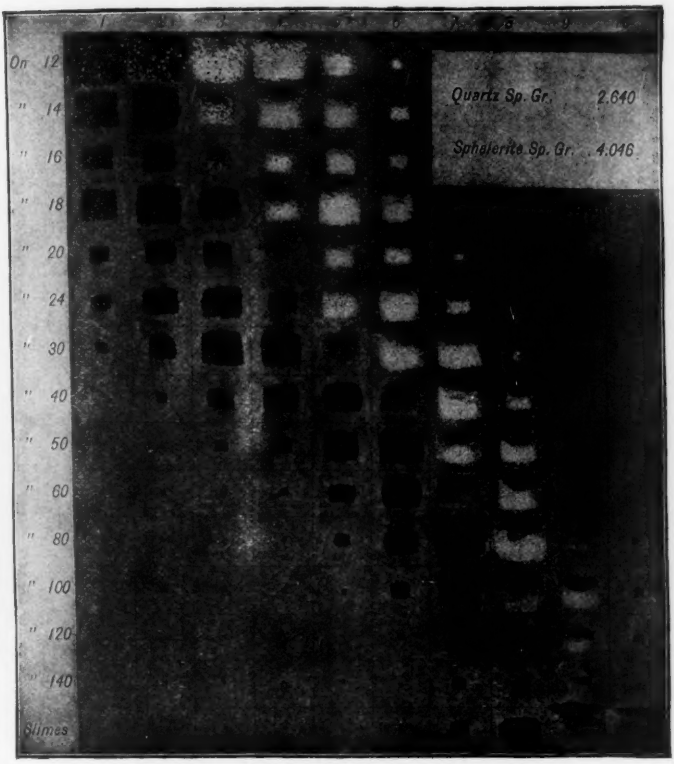
TABLE XVIII.

ESTIMATED PERCENTAGE OF PYRRHOTITE IN THE HILLS OF PLATE IX.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	50	1	.....	.....	.....	.....	.....	.....	.....
14	100	100	10	1	.....	.....	.....	.....	.....	.....
16	100	100	50	2	1	.....	.....	.....	.....	.....
18	100	100	95	25	1	.....	.....	.....	.....	.....
20	100	100	100	50	1	1	.....	.....	.....	.....
24	100	100	100	90	10	1	1	.....	.....	.....
30	100	100	100	98	50	10	2	2	40	.....
40	100	100	100	100	98	50	5	4	40	.....
50	100	100	100	100	100	90	10	4	35	40
60	100	100	100	100	100	98	50	5	25	40
80	100	100	100	100	100	100	90	10	20	50
100	100	100	100	100	100	100	100	50	25	50
120	100	100	100	100	100	100	100	98	25	50
140	100	100	100	100	100	100	100	100	25	50
Slimes	100	100	100	100	100	100	100	100	65	60

For the weights of the hills in columns 5, 6, and 7, see Table XXXIII.

PLATE X.



Separation of Quartz and Sphalerite by Pointed Tube and Sieves.

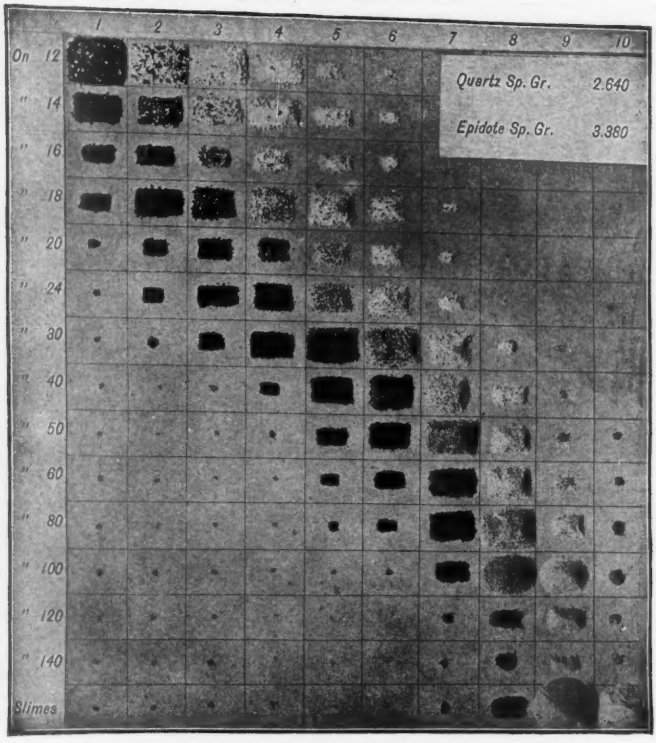
TABLE XIX.

ESTIMATED PERCENTAGE OF SPHALERITE IN THE HILLS OF PLATE X.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	99.5	80	10	.....	.....	.....	.....	.....	.....	.....
14	100	99	40	.....	.....	.....	.....	.....	.....	.....
16	100	100	60	2	.....	.....	.....	.....	.....	.....
18	100	100	80	10	.....	.....	.....	.....	.....	.....
20	100	100	99	50	2	.....	.....	.....	.....	.....
24	100	100	100	85	10	1	.....	1	.....	.....
30	100	100	100	99	50	10	2	1	.....	.....
40	100	100	100	100	98	50	5	1	25	.....
50	100	100	100	100	100	90	20	2	60	.....
60	100	100	100	100	100	99	50	5	70	.....
80	100	100	100	100	100	100	75	15	50	90
100	100	100	100	100	100	100	95	40	40	90
120	100	100	100	100	100	100	100	50	40	90
140	100	100	100	100	100	100	100	60	40	90
Slimes	100	100	100	100	100	100	100	85	60	85

For the weights of the hills in columns 5, 6, and 7, see Table XXXIV.

PLATE XI.



Separation of Quartz and Epidote by Pointed Tube and Sieves.

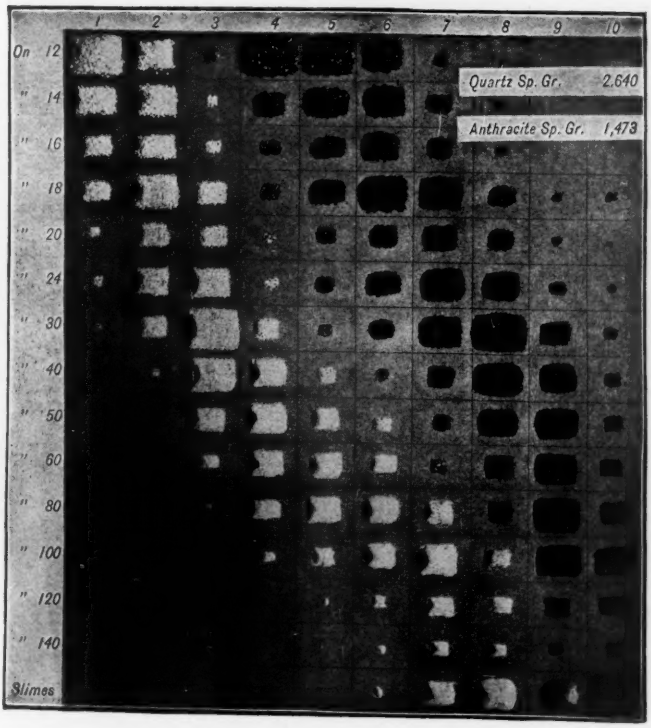
TABLE XX.

ESTIMATED PERCENTAGE OF EPIDOTE IN THE HILLS OF PLATE XI.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	95	50	3	.....	.....	.....	.....	.....	.....	.....
14	100	90	20	3	.....	.....	.....	.....	.....	.....
16	100	95	50	5	.....	.....	.....	.....	.....	.....
18	100	100	80	40	5	.....	.....	.....	.....	.....
20	100	100	100	70	25	.....	.....	.....	.....	.....
24	100	100	100	97	50	10	.....	.....	.....	.....
30	100	100	100	100	75	50	3	3	50	.....
40	100	100	100	100	95	70	25	5	50	.....
50	100	100	100	100	100	95	50	10	50	.....
60	100	100	100	100	100	100	60	25	25	95
80	100	100	100	100	100	100	75	50	25	95
100	100	100	100	100	100	100	100	75	25	75
120	100	100	100	100	100	100	100	90	50	50
140	100	100	100	100	100	100	100	97	50	40
Slimes	100	100	100	100	100	100	100	100	50	25

For the weights of the hills in columns 5, 6, and 7, see Table XXXV.

PLATE XII.



Separation of Quartz and Anthracite by Pointed Tube and Sieves.

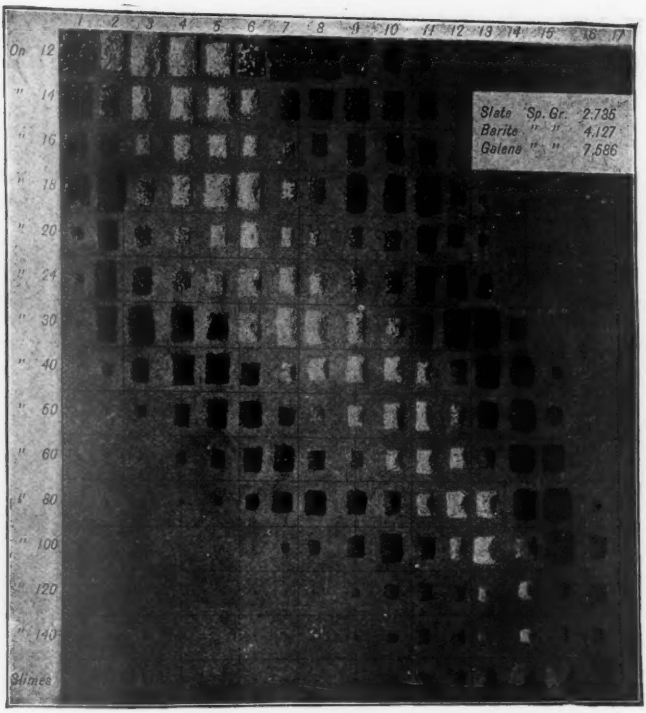
TABLE XXI.

ESTIMATED PERCENTAGE OF ANTHRACITE IN THE HILLS OF PLATE XII.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	.....	.....	80	99	100	100	100	100	.....	.....
14	.....	.....	5	98	100	100	100	100	.....	.....
16	.....	.....	1	90	100	100	100	100	100	.....
18	.....	.....	.....	65	100	100	100	100	100	100
20	.....	.....	.....	45	100	100	100	100	100	100
24	.....	.....	.....	5	100	100	100	100	100	100
30	.....	.....	.....	2	50	100	100	100	100	100
40	.....	.....	.....	.....	4	50	100	100	100	100
50	.....	.....	.....	.....	.....	5	95	100	100	100
60	.....	.....	.....	.....	.....	.....	40	100	100	100
80	.....	.....	.....	.....	.....	.....	5	95	100	100
100	.....	.....	.....	.....	.....	.....	.....	4	100	100
120	.....	.....	.....	.....	.....	.....	.....	1	95	98
140	.....	.....	.....	.....	.....	.....	.....	.....	90	98
Slimes	.....	.....	.....	.....	.....	.....	.....	.....	35	60

For the weights of the hills in columns 5, 6, and 7, see Table XXXVI.

PLATE XIII.



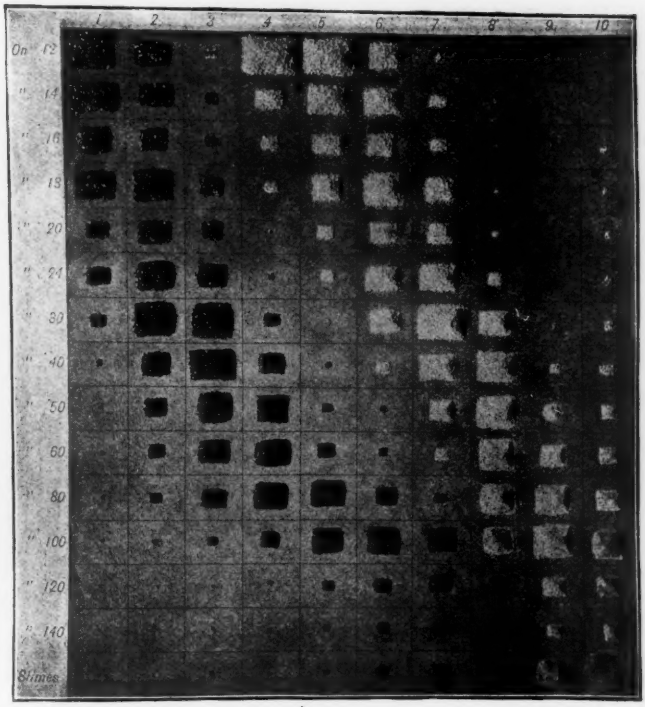
Separation of Slate, Barite, and Galena by Pointed Tube and Sieves.

TABLE XXII.

ESTIMATED PERCENTAGE OF BARITE IN THE HILLS OF PLATE XIII.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12 . .	....	80	100	100	100	50	....	....	....	....	....	....	....	....	....	....	....
14 . .	....	10	99	100	100	98	5	1	1	....	....	....	....	....	....	....	....
16 . .	....	....	95	100	100	100	50	2	1	....	....	....	....	....	....	....	....
18 . .	....	....	50	95	100	100	95	20	1	1	....	....	....	....	....	....	....
20 . .	....	....	10	75	99	100	100	80	10	1	....	....	....	....	....	....	....
24 . .	....	....	....	50	90	100	100	95	45	5	1	1	....	....	....	....	....
30 . .	....	....	....	2	25	80	100	100	90	90	5	1	1	....	....	....	....
40 . .	....	....	....	....	....	10	75	100	100	100	95	5	1	1	1	....	....
50 . .	....	....	....	....	....	....	15	60	99	100	100	75	5	1	2	....	....
60 . .	....	....	....	....	....	....	....	2	40	90	100	98	20	2	2	....	....
80 . .	....	....	....	....	....	....	....	....	2	25	90	100	90	5	5	10	....
100 . .	....	....	....	....	....	....	....	....	....	....	5	60	98	55	5	10	40
120 . .	....	....	....	....	....	....	....	....	....	....	....	5	80	98	10	10	20
140 . .	....	....	....	....	....	....	....	....	....	....	....	....	50	98	20	5	20
Slimes .	....	....	....	....	....	....	....	....	....	....	....	....	30	50	75	20	10

PLATE XIV.



Separation of Quartz (Sp. Gr. 2·64) and Galena (Sp. Gr. 7·586) by Pulsion-Jig and Sieves.

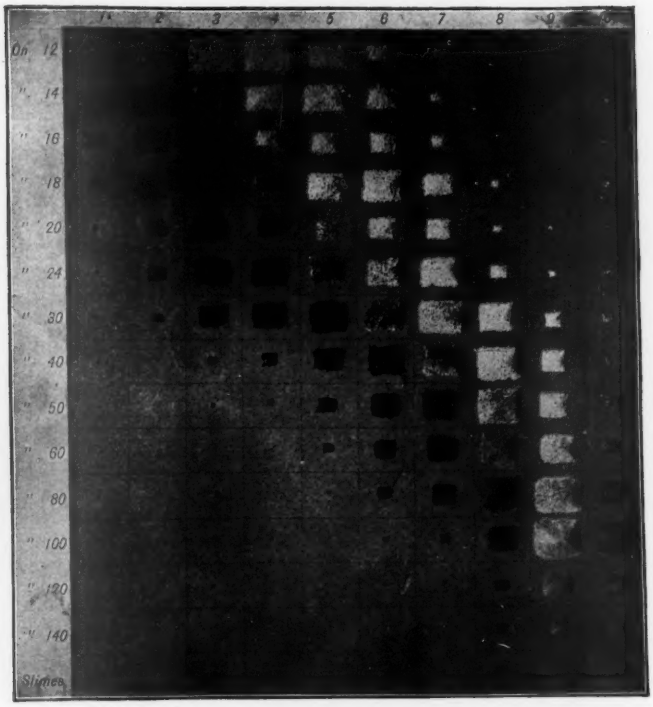
TABLE XXIII.

ESTIMATED PERCENTAGE OF GALENA IN THE HILLS OF PLATE XIV.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	100	50	.....	.....	.....	.....	.....	.....	.....
14	100	100	99	.....	.....	.....	.....	.....	.....	.....
16	100	100	100	.....	.....	.....	.....	.....	.....	.....
18	100	100	100	2	.....	.....	.....	.....	.....	.....
20	100	100	100	50	.....	.....	.....	.....	.....	10
24	100	100	100	90	.....	.....	.....	.....	.....	15
30	100	100	100	100	5	.....	.....	.....	.....	15
40	100	100	100	100	95	5	.....	.....	.....	15
50	100	100	100	100	100	50	3	.....	.....	10
60	100	100	100	100	100	100	5	1	.....	10
80	100	100	100	100	100	100	90	3	.....	5
100	100	100	100	100	100	100	100	40	5	50
120	100	100	100	100	100	100	100	60	10	40
140	100	100	100	100	100	100	100	80	10	40
Slimes	100	100	100	100	100	100	100	100	60	50

For the weights of the hills in columns 5, 6, and 7, see Table XL.

PLATE XV.



Separation of Quartz (Sp. Gr. 2.64) and Sphalerite (Sp. Gr. 4.046) by Pulsion-Jig and Sieves.

TABLE XXIV.

ESTIMATED PERCENTAGE OF SPHALERITE IN THE HILLS OF PLATE XV.

SIEVE-MESH.	1	2	3	4	5	6	7	8	9	10
12	100	80	5	.....	.....	.....	.....	.....	.....	.....
14	100	100	50	.....	.....	.....	.....	.....	.....	.....
16	100	100	90	3	.....	.....	.....	.....	.....	40
18	100	100	100	50	5	1	.....	.....	.....	15
20	100	100	100	95	40	1	.....	.....	.....	50
24	100	100	100	100	75	20	1	.....	.....	10
30	100	100	100	100	98	50	5	1	.....	40
40	100	100	100	100	100	95	50	3	1	40
50	100	100	100	100	100	100	90	30	2	40
60	100	100	100	100	100	100	100	40	5	50
80	100	100	100	100	100	100	100	60	30	75
100	100	100	100	100	100	100	100	75	40	70
120	100	100	100	100	100	100	100	100	50	60
140	100	100	100	100	100	100	100	100	50	50
Slimes	100	100	100	100	100	100	100	100	60	50

For the weights of the hills in columns 5, 6, and 7, see Table XLI.

TABLE XXV.

QUARTZ AND COPPER (Plate I).

SIEVE-MESH.	BULB No. 5.		BULB No. 6.		BULB No. 7.	
	Copper, Grams.	Quartz, Grams.	Copper, Grams.	Quartz, Grams.	Copper, Grams.	Quartz, Grams.
12 . . .	.....	10.7193	.....	2.0011	.....	.....
14 . . .	.....	6.3910	.0452	4.4756	.....	.1486
16 . . .	.....	3.1724	.0270	2.6766	.....	.2097
18 . . .	.....	2.5210	.1236	12.2374	.....	2.3365
20 . . .	.....	.1277	.0277	2.7450	.....	1.7427
24 . . .	.0010	.0476	.0348	3.4430	.....	6.3275
30 . . .	.0305	.0009	.1278	1.1504	.....	11.2542
40 . . .	.2008	.....	.2048	.0108	.0207	2.0472
50 . . .	.6324	.....	.2115	.0002	.0147	.1947
60 . . .	1.8367	.....	.2851	.....	.0179	.0219
80 . . .	12.8308	.....	2.4554	.....	.1117	.0062
100 . . .	19.6367	.....	12.2217	.....	2.2148	.0224
120 . . .	6.8088	.....	9.5750	.....	5.4133	.....
140 . . .	1.6049	.....	2.0052	.....	1.1046	.....
Slimes . .	5.2685	.....	16.8152	.....	39.3308	.....
Total . .	48.8511	22.9799	44.1600	28.7401	48.2285	24.3116

obtained, the relative proportions of the two minerals were estimated by the eye, and the total weight was divided between them in accordance with this estimate.

In order to throw light upon the question of interstitial currents, it was necessary to obtain the ratio of diameters for the particles of quartz and galena, for example, when the two minerals had arrived at equilibrium through the action of the upward current. The values given in Tables XXV to XXXVI for the whole series of minerals were used for this purpose.

The particles in any given column may be assumed to be in equilibrium because the light and heavy materials there drawn out together have had ample time to choose their partners.

The mode of computation for any given column or bulb may

TABLE XXVI.

QUARTZ AND GALENA (Plate II*b*).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Galena, Grams.	Quartz, Grams.	Galena, Grams.	Quartz, Grams.	Galena, Grams.	Quartz, Grams.
12 . . .	.....	8.281	.....	0.0880	.....	.....
14 . . .	.....	11.713	.....	1.447	.....	.....
16 . . .	.....	5.525	.....	1.946	.....	0.0943
18 . . .	.....	6.412	.....	10.582	.....	0.3535
20 . . .	.....	0.4273	.....	4.436	.....	0.5507
24 . . .	.....	0.1306	.....	6.790	.....	3.465
30 . . .	.....	0.0129	.....	3.268	.....	12.982
40 . . .	0.0339	.....	.....	0.0570	.....	5.897
50 . . .	0.2403	.....	0.0485	.....	.....	1.633
60 . . .	1.696	.....	0.1170	.....	.....	0.1737
80 . . .	16.335	.....	4.918	.....	0.1950	.....
100 . . .	7.705	.....	21.141	.....	2.955	.....
120 . . .	0.2278	.....	4.523	.....	3.738	.....
140 . . .	0.0580	.....	2.378	.....	3.382	.....
Slimes . .	0.1310	.....	1.902	.....	25.040	.....
Total . .	26.4270	32.5018	35.0275	28.6140	35.3100	25.1492

be shown by taking as an example Plate II*b* and bulb No. 5 of Table XXVI. Here the average diameter of the quartz particles was obtained by multiplying all the quartz weights in columns 5 by their diameters, and dividing the sum of the products by the sum of the weights. The galena figures in column 5, treated similarly, give an average diameter for the galena particle. This diameter of quartz is then divided by the diameter of the galena. In like manner computations were made upon all of the eleven minerals, and these interstitial factors are given for all the minerals except magnetite in Table XXXVII.

Lest the proportions of the two minerals (equal volumes) used in the pointed tube tests (Plates I to XII) might have influenced the results, a trial test for comparison with Plate II*b* was made, using

TABLE XXVII.

QUARTZ AND GALENA (Ratio 16 : 1 by Volume).

SIEVE-MESH.	BULB NO. 4.	
	Quartz, Grams.	Galena, Grams.
12	3.598	.....
14	3.744	.....
16	2.295	.....
18	5.791	.....
20	1.320	.....
24	1.916	.....
30	0.880	0.098
40	0.0336	0.0112
50	0.0017	0.0323
60	.....	0.1152
80	.....	0.723
100	.....	1.409
120	.....	0.233
140	.....	0.0576
Slimes	.....	0.0737
Total	19.5793	2.7530

a quantity of galena equal to about one sixteenth of the volume of quartz, instead of equal volumes of the two minerals. The 4th, 5th, and 6th bulbs were sized, and gave hills apparently at the same points as shown in Plates II*a* and II*b*. To demonstrate the point still further, weights and computations were made upon the 4th bulb (Table XXVII) and yielded the ratio of the diameter of the galena particle to that of the quartz.

1 : 5.966.

This ratio is practically the same as those given in Table XXXVII for galena and quartz, and therefore demonstrates that the relative quantities of the two minerals have nothing to do with the law of interstitial currents. The ratio of diameter is fixed.

The foregoing experiments show that, under the conditions existing in the pointed tube, the diameter ratio of galena and quartz in equilibrium together, when interstitial currents have done their whole work, is about 1 : 6 for particles ranging between 10-mesh and 100-mesh. They further show that interstitial currents have a real existence, and have decidedly advanced the ratio from the equal-settling particles of the free falling test which is given by Rittinger as 1 : 4, and which has been found in this investigation for 10 to 12 mesh quartz as 1 : 3.75. My tests do not, however, substantiate the claim made by Professor Munroe that galena and quartz will not come to equilibrium in interstitial currents until a ratio of 1 : 30 for their diameters has been reached.

Fig. 6.

Reversible Free-fall Tube.

One or two interesting facts may be noted here, although they are on one side from the main thread of this paper.

In the first galena trial (Plate II*a*) it was found that fine galena appeared in the first drawing below 30-mesh. This may be attributed wholly to particles abraded during the subsequent sifting operation. To test the question, the galena quartz lot was mixed up thoroughly and run over again (Plate II*b*); and this time the fine galena below the main range of galena hills is much reduced, proving the conjecture to be substantially correct.

Again, the fall velocities of these different heaps were taken in a tube (Figure 6), designed by C. Le Neve Foster, in which by inverting the tube the measure may be taken over and over. The results are here given. They show that, for example, on the 18-mesh line grains of galena in No. 1 are faster than No. 2, and No. 2 than No. 3, also for the quartz Nos. 4, 5, 6, and 7 fall in that order, 4 being the fastest and 7 the slowest; 4 contains the 18-mesh grains that are nearest to a cube; 7 are the flat oyster shells that fall much slower. Results of these trials are given in Table XXXVIII.

In this test a group of 20 or 30 grains was timed. When the

TABLE XXVIII.

QUARTZ AND WOLFRAMITE (Plate III).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Wolframite, Grams.	Quartz, Grams.	Wolframite, Grams.	Quartz, Grams.	Wolframite, Grams.	Quartz, Grams.
12 . . .	.....	5.0224	.....	0.0723	.....	.....
14 . . .	.....	8.4741	.....	0.7525	.....	.....
16 . . .	.....	5.2412	.....	1.0360	.....	0.0342
18 . . .	.....	9.1827	.....	7.5598	.....	0.2932
20 . . .	.....	1.3058	.....	3.5209	.....	0.3887
24 . . .	.....	1.1077	.....	8.2641	.....	2.4168
30 . . .	0.0418	0.3766	.....	6.8889	.....	10.4951
40 . . .	0.2220	0.0392	0.0453	0.8611	.....	10.0156
50 . . .	0.8650	0.0455	0.0499	0.1977	.....	4.7618
60 . . .	3.7694	.....	0.3763	0.0418	0.0173	1.5664
80 . . .	12.1549	.....	3.9501	0.2079	0.0690	0.5311
100 . . .	6.8694	.....	15.6509	.....	1.5409	0.1865
120 . . .	0.3685	.....	3.2758	.....	1.7262	.....
140 . . .	0.0911	.....	1.4869	.....	0.7340	.....
Slimes . .	0.0886	.....	6.1610	.....	18.2780	.....
Total . .	24.4707	30.7952	30.9962	29.4030	22.3654	30.6894

average grain passed the upper and lower marks the time was taken. The results are therefore averages. In the light of these facts the remarkable resemblance between these two tests of galena and quartz (Plates II*a* and II*b*) becomes more interesting; for it is probable that, with certain latitude, the particles of the first test found their way back to the same identical heap in the second test. This principle of almost absolute predestination of particles for their own appointed places in ore dressing is very important. It was mentioned by me in Chicago last summer, in discussing the paper of Oberbergrath Bilhartz, under the heading "Once Middlings, Always Middlings" (*Trans.* 22, 700).

It will be noticed that the light color of the slimes of No. 9 in Plates I to XII is almost always marked when compared with

TABLE XXIX.

QUARTZ AND ANTIMONY (Plate IV).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Antimony, Grams.	Quartz, Grams.	Antimony, Grams.	Quartz, Grams.	Antimony, Grams.	Quartz, Grams.
12 . . .	.....	10.8059	.....	0.4286	.....	.....
14 . . .	.....	10.5023	.....	2.3922	.....	0 0973
16 . . .	.....	3.8306	.....	2.7134	.....	0.2042
18 . . .	.....	4.5723	.....	9.6878	.....	2 1545
20 . . .	.....	0.4613	.....	2.9766	.....	1.7760
24 . . .	.....	0.2330	.....	3.9996	.....	5.8914
30 . . .	0.0377	0.0377	.....	1.5920	.....	12.5619
40 . . .	0.8874	.....	0.0390	0.0390	.....	4.3622
50 . . .	6.8722	.....	0.0316	0.5894	.....	1.1711
60 . . .	10.1563	.....	3.1825	.....	0.0992	0.1488
80 . . .	8.5035	.....	14.3174	.....	1.0615	0.1180
100 . . .	1.2058	.....	13.5745	.....	9.6491	.....
120 . . .	.....	.....	1.3978	.....	4.6588	.....
140 . . .	.....	.....	0.3979	.....	1.5357	.....
Slimes . .	.....	.....	0.9932	.....	14.3481	.....
Total . .	27.6629	30.4431	33.9339	24.4186	31.3524	28 4854

its neighbors on the right and left of it. This being a truly sorted product, the finer dark mineral hides itself beneath the coarser light mineral. This shows in all the sets except copper, which had no slimes; magnetite, which had almost none; and epidote, the fine powder of which is extremely light colored, and of which the 10th slimes are therefore as light as the 9th.

The ultimate effect of an upward current of water upon sands of two specific gravities is shown in Plates I to XIII inclusive. This, then, is the ultimate equilibrium, which is approached but never quite reached by the pulsion movement of a jig. The ideas conveyed by these photographs may be represented geometrically by Figure 7, in which each cone stands for a column of particles

TABLE XXX.

QUARTZ AND CASSITERITE (Plate V).

SIEVE-MESH.	BULB No. 5.		BULB No. 6.		BULB No. 7.	
	Cassiterite, Grams.	Quartz, Grams.	Cassiterite, Grams.	Quartz, Grams.	Cassiterite, Grams.	Quartz, Grams.
12 . . .	.....	4.0757	.....	0 0274	.....	.....
14 . . .	.....	7.3256	.....	0.4636	.....	.....
16 . . .	.....	5.0848	.....	0.6899	.....	0.0094
18 . . .	.....	10.2372	.....	6.1156	.....	0.2319
20 . . .	.....	1.5721	.....	3.4824	.....	0.3015
24 . . .	0.0241	1.1806	.....	7.7527	.....	1.6953
30 . . .	0.2061	0.3092	.....	7 8932	.....	10.8524
40 . . .	0.3305	0.0102	0.0551	1.0469	.....	8.7152
50 . . .	1.2270	.....	0.0864	0.1296	.....	4.8594
60 . . .	6.6046	.....	0.9265	0.1030	0.0768	1.8441
80 . . .	12.2446	.....	9.3352	....	0.3125	0.7292
100 . . .	4.3263	.....	16.2333	.....	3.5888	0.8972
120 . . .	0.3272	.....	2.3566	.....	2.4621	.....
140 . . .	0.0748	.....	0.6666	.....	0.7038	.....
Slimes . .	0.1580	.....	4.6162	.....	15.6383	.....
Total . .	25.5232	29.7954	34.2759	27.7043	22.7823	30 1356

Fig. 7.

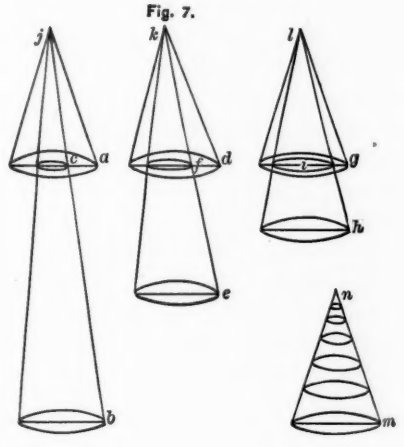


TABLE XXXI.

QUARTZ AND ARSENOPYRITE (Plate VI).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Arsenopyrite, Grams.	Quartz, Grams.	Arsenopyrite, Grams.	Quartz, Grams.	Arsenopyrite, Grams.	Quartz, Grams.
12 . . .	.....	6.3982	.....	1.0015	.....	.....
14 . . .	.....	9.0563	.....	3.2585	.....	0.1371
16 . . .	0.0993	4.8676	.....	2.1703	.....	0.2182
18 . . .	0.3430	8.2314	0.0945	9.3590	.....	1.4163
20 . . .	0.0805	1.2618	0.0316	3.1256	.....	0.9750
24 . . .	0.2363	1.3387	0.1278	6.2628	0.0362	3.5838
30 . . .	0.7460	0.1867	0.5144	4.6292	0.2451	12.0106
40 . . .	0.9764	0.0199	0.8400	0.3600	0.7444	6.6991
50 . . .	2.9162	.....	0.9052	0.0476	0.9213	2.7638
60 . . .	5.3491	.....	2.4436	.....	0.8064	0.9856
80 . . .	6.0430	.....	7.6572	.....	2.1537	0.5384
100 . . .	0.8948	.....	6.9215	.....	7.7638	.....
120 . . .	.....	.....	0.7400	.....	2.5433	.....
140 . . .	.....	.....	0.1858	.....	0.9098	.....
Slimes . .	.....	.....	0.4976	.....	8.7290	.....
Total . .	17.6846	31.3606	20.9592	30.2145	24.8530	29.3279

of a single mineral species, as they would be arranged in an upward current of water. The heaviest grain with the largest diameter is represented by the diameter of the base of the cone (*m*); the lightest and smallest is represented by the apex of the cone (*n*). Two cones placed together, as *a* and *b*, represent two minerals of different specific gravity treated together in a pointed tube. Their vertices will be together, because the finest dust of the two will settle at almost the same rate, that is, with almost no velocity.

The largest particles, represented by the bases of the two cones, will settle at very different rates, and the relative lengths of the cones may be chosen to represent the relative positions in the pointed tube of the coarsest particles of each of the two minerals. For example, the cone *b* may represent galena, and *a* quartz, as they would ap-

TABLE XXXII.

QUARTZ AND CHALCOCITE (Plate VII).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Chalcocite, Grams.	Quartz, Grams.	Chalcocite, Grams.	Quartz, Grams.	Chalcocite, Grams.	Quartz, Grams.
12 . . .	.....	6.4328	.....	0.3836	0.0103	0.0212
14 . . .	.....	9.4660	.....	2.2082	0.0235	0.0938
16 . . .	.....	3.8929	0.0217	2.1473	0.0049	0.0925
18 . . .	.....	5.6878	0.0992	9.8193	0.0532	1.0115
20 . . .	0.0069	0.6846	0.0341	3.3762	0.0413	0.7848
24 . . .	0.1514	0.2812	0.0692	6.8519	0.1946	3.6983
30 . . .	1.1977	0.0630	0.8250	3.2998	1.6990	10.6278
40 . . .	6.1287	.....	0.7190	0.4794	3.0624	3.0624
50 . . .	8.8292	.....	3.2620	0.0329	1.8900	0.6300
60 . . .	4.9825	.....	6.0144	.....	1.7927	0.0944
80 . . .	1.5220	.....	8.0520	.....	7.2729	.....
100 . . .	0.0491	.....	2.3114	.....	11.3342	.....
120 . . .	.....	.....	0.0897	.....	1.7587	.....
140 . . .	.....	.....	0.0195	.....	0.7359	.....
Slimes . .	.....	.....	0.0505	.....	2.7702	.....
Total . .	22.8675	26.5083	21.5677	28.5986	32.6438	20.1167

pear when in equilibrium in a pointed tube. The cones *d* and *e* may represent quartz and arsenopyrite, and *g* and *h* may represent quartz and epidote. From these main facts the conclusion is natural. The particle *c* of galena, which is adjacent to *a* of quartz, is very small. It is much smaller than the interstices between the quartz particles (*a*). The same relation holds between all the adjacent particles of cones *aj* and *cj*. The particle *f* of arsenopyrite is larger than *c;* it is about equal to the interstices between the particles of quartz (*d*); and consequently all the particles of arsenopyrite in the little cone *fk* will bear the same relation to the adjacent quartz particles, they all being equal to the interstices in the cone (*dk*). The particles (*i*) of epidote will be larger than the interstices between the quartz particles (*g*), and this

TABLE XXXIII.

QUARTZ AND PYRRHOTITE (Plate IX).

SIEVE-MESH.	BULB NO. 4.		BULB NO. 5.		BULB NO. 6.	
	Pyrrhotite, Grams.	Quartz, Grams.	Pyrrhotite, Grams.	Quartz, Grams.	Pyrrhotite, Grams.	Quartz, Grams.
12 . . .	.....	12.9000	.....	2.8578	.....	0.1936
14 . . .	0.0854	8.4606	.....	5.6642	.....	0.6740
16 . . .	0.0489	2.3944	0.0362	3.5878	.....	0.6461
18 . . .	0.7106	2.1317	0.0836	8.2714	.....	4.2311
20 . . .	0.3483	0.3483	0.0111	1.0969	0.0233	2.3082
24 . . .	1.3307	0.1478	0.2680	2.4115	0.0558	5.5242
30 . . .	9.5668	0.1950	1.8550	1.8550	0.8274	7.4467
40 . . .	6.9965	.....	4.4928	0.0917	1.6844	1.6844
50 . . .	3.3025	.....	5.5675	.....	2.6784	0.2976
60 . . .	0.5011	.....	3.8000	.....	5.0036	0.1021
80 . . .	.....	.....	1.2862	.....	8.5450	.....
100 . . .	.....	.....	.....	.....	4.9831	.....
120 . . .	.....	.....	.....	.....	0.4192	.....
140 . . .	.....	.....	.....	.....	0.1300	.....
Slimes . .	.....	.....	.....	.....	0.1617	.....
Total . .	22.8908	26.5778	17.4004	25.8363	24.5119	23.1080

relation will hold all the way up for adjacent particles in the cones *gl* and *il*.

The ultimate result of the pointed tube, the *Spitzlutte*, the Lake Superior separator, and of the pulsion action of the jig is to associate together particles of the two minerals that are to be separated, in which the ratio of the grains lies in one of these three classes:

1. The lesser, higher specific gravity grain is smaller than the quartz interstices.

2. The lesser, higher specific gravity grain is equal to the quartz interstices.

3. The lesser, higher specific gravity grain is greater than the quartz interstices.

TABLE XXXIV.

QUARTZ AND SPHALERITE (Plate X).

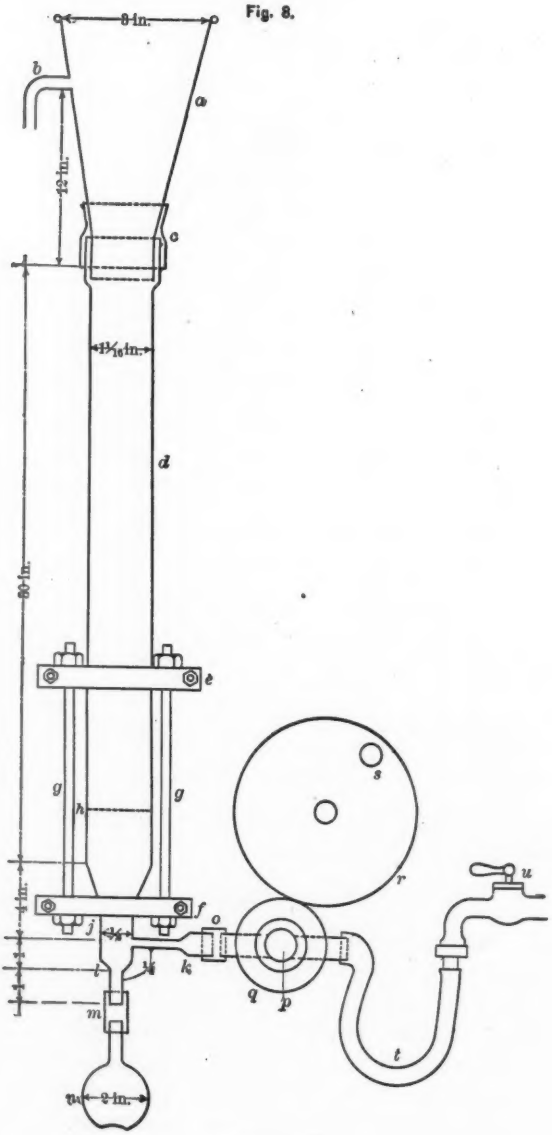
SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Sphalerite, Grams.	Quartz, Grams.	Sphalerite, Grams.	Quartz, Grams.	Sphalerite, Grams.	Quartz, Grams.
12 . . .	.....	3.4518	.....	0.1900	.....	.....
14 . . .	.....	4.4504	.....	0.5707	.....	.....
16 . . .	.....	3.1366	.....	0.4898	.....	.....
18 . . .	.....	8.7064	.....	3.9642	.....	0.0922
20 . . .	0.0539	2.6426	.....	1.8967	.....	0.1643
24 . . .	0.3923	3.5302	0.0665	6.5786	.....	0.9541
30 . . .	2.6226	2.6226	0.1017	10.0720	0.1247	6.1078
40 . . .	6.3358	0.1293	2.7952	2.7952	0.4212	8.0019
50 . . .	4.6660	.....	5.9173	0.6575	1.3300	5.3187
60 . . .	1.5942	.....	5.6285	0.0569	3.1622	3.1622
80 . . .	0.3894	.....	3.7332	.....	6.4017	2.1339
100 . . .	.....	.....	0.6867	.....	6.4078	0.3373
120 . . .	.....	.....	.....	.....	0.6962	.....
140 . . .	.....	.....	.....	.....	0.2921	.....
Slimes . .	.....	.....	.....	.....	0.8976	.....
Total . .	16.0542	28.6699	18.9291	27.2716	19.7335	26.2724

These laws are important, and should be recognized and duly considered when mills are planned.

III. ACCELERATION.

Rittinger, having found that jigs save galena of smaller sizes than his formula of 1866 allows, worked out in his appendix of 1870 the theory of acceleration to account for that fact, showing that a particle of galena which is equal-settling with a particle of quartz reaches its maximum velocity in perhaps one tenth the time required by the quartz. The oft-repeated pulsations of a jig give the galena particles a decided advantage over the quartz, placing beside the quartz, when equilibrium is reached, a much smaller particle of galena than we should expect according to the law of equal-settling

Fig. 8.



PULSION-JIG.

TABLE XXXV.

QUARTZ AND EPIDOTE (Plate XI).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Epidote, Grams.	Quartz, Grams.	Epidote, Grams.	Quartz, Grams.	Epidote, Grams.	Quartz, Grams.
12 . . .	.....	1.1376	.....	0.0858	.....	.....
14 . . .	.....	2 6366	.....	0.4537	.....	.....
16 . . .	.....	2.1569	.....	0.4406	.....	.....
18 . . .	0.4433	8.4234	.....	3.3701	.....	0.1179
20 . . .	0.7673	2.3020	.....	2 1856	.....	0.1693
24 . . .	2.7109	2.7109	0.5945	5.3501	.....	0 8444
30 . . .	8.7481	2.9161	6.1561	6.1561	0.2146	6.9373
40 . . .	5 0263	0.2645	5 8478	2 5062	2.1476	6.4429
50 . . .	1.6755	.....	5.0005	0.2632	4.6980	4.6980
60 . . .	0.4066	.....	1.9449	.....	4.1074	2.7382
80 . . .	0.0816	.....	0.4786	.....	5.0657	1.6886
100 . . .	.....	.....	.....	.....	2.2078	.....
120 . . .	.....	.....	.....	.....	0.1084	.....
140 . . .	.....	.....	.....	.....	.....	.....
Slimes . .	.....	.....	.....	.....	.....	.....
Total . .	19 8596	22.5480	20.0224	20.8114	18.5495	23.6366

particles. He concludes that the excess of jigging power over that indicated by the law of equal-settling particles is due to acceleration. Unfortunately, he has not given a ratio of diameters of quartz and galena which represents equilibrium with regard to acceleration.

To test this question of acceleration I have designed a pulsion-jig or modified *Setzpumpe*, which is shown in Figure 8. It consists of a tin funnel (*a*), with overflow (*b*), connected by rubber connector (*c*) to a glass tube (*d*), cut apart at *h* for the insertion of a disk of sieve-cloth. The two parts are held together by two clamps (*e* and *f*) and two bolts (*gg*), and the leaky joint at *h* is made tight by a belt of rubber plaster. The tube has a branch (*k*) joined by rubber connector (*o*) to a common plug-cock (*p*), provided with a gear-

TABLE XXXVI.

QUARTZ AND ANTHRACITE (Plate XII).

SIEVE-MESH.	BULB No. 6.		BULB No. 7.		BULB No. 8.	
	Quartz, Grams.	Anthracite, Grams.	Quartz, Grams.	Anthracite, Grams.	Quartz, Grams.	Anthracite, Grams.
12 . . .	.....	2.5000	.....	0.0732	.....	0.0022
14 . . .	.....	2.7538	.....	0.4072	.....	0 0133
16 . . .	.....	2.0190	.....	0.4554	.....	0.0296
18 . . .	.....	4 6107	.....	1.7692	.....	0.4063
20 . . .	.....	0.8121	.....	1.2981	.....	0.3932
24 . . .	.....	1.2677	.....	3.0468	.....	1.6826
30 . . .	.....	0.4710	.....	2.8781	.....	5.3864
40 . . .	0.0504	0.0504	.....	0.6647	.....	3.6871
50 . . .	0.3122	0.0164	0.0112	0 2118	.....	1.9739
60 . . .	0.9343	.....	0.1603	0.1068	.....	0.8904
80 . . .	3.0169	.....	1.4114	0.0743	0.0273	0.5186
100 . . .	2.2728	.....	1.1505	.....	1.1045	0.0460
120 . . .	0.1862	.....	0.5641	.....	0.5585	0.0056
140 . . .	0.0534	.....	0.2224	.....	0.2224	.....
Slimes . .	0.0942	.....	1.8673	.....	3.9229	.....
Total . .	6.9204	14.5011	5 3872	10.9856	5 8356	15.0352

wheel (*q*), which intermeshes with a larger gear (*r*) having a crank (*s*) turned by hand. Water is supplied through the rubber hose (*t*) and the hydrant (*u*). The lower end of the tube is drawn down to one quarter inch in diameter at *l*, and by rubber connector (*m*) is joined to a bulb (*n*) for receiving what passes through the sieve.

The method of operating this pulsion-jig is simply to turn on the water gently at *u* and revolve the crank (*s*) at the speed desired. The revolution of the plug-cock (*p*) makes and breaks the water connection, and the rubber tube (*t*) is elastic enough to act as an accumulator for the instant that the water is shut off. The sand fed in at the funnel (*a*) quickly falls to the sieve (*h*), and then receives a series of intermittent upward pulsations from the movement of the

TABLE XXXVII.

INTERSTITIAL FACTORS, OR MULTIPLIERS FOR OBTAINING THE DIAMETER OF THE PARTICLE OF QUARTZ WHICH IN THE POINTED TUBE WILL BE IN EQUILIBRIUM WITH THE MINERAL SPECIFIED.

QUARTZ AND	Ratio of the Diameter of the Heavier to that of the Lighter Mineral.				
	Column 4.	Column 5.	Column 6.	Column 7.	Column 8.
Copper	.....	8.373	7.791	9.629	.....
Galena	.....	6.325	5.656	5.544	.....
Wolframite	.....	4.924	5.381	5.161	.....
Antimony	.....	4.816	4.932	4.942	.....
Cassiterite	.....	4.944	4.713	4.436	.....
Arsenopyrite	.....	3.847	3.747	3.617	.....
Chalcocite	.....	3.464	3.246	2.636	.....
Pyrrhotite	2.640	2.795	2.988	.....	.....
Sphalerite	.....	2.308	2.030	2.042	.....
Epidote	.....	1.702	1.610	1.571	.....
Anthracite	.....	.....	5.540	5.569	5.724

water. The sand is therefore subjected to an upward current of water at one instant, which remains stagnant the next instant. These pulsations may be given at almost any rate up to 800 per minute.

This instrument seems well calculated to answer the question, Does Rittinger's acceleration, due to intermittent upward pulsations, add anything to the effect of Munroe's interstitial currents?

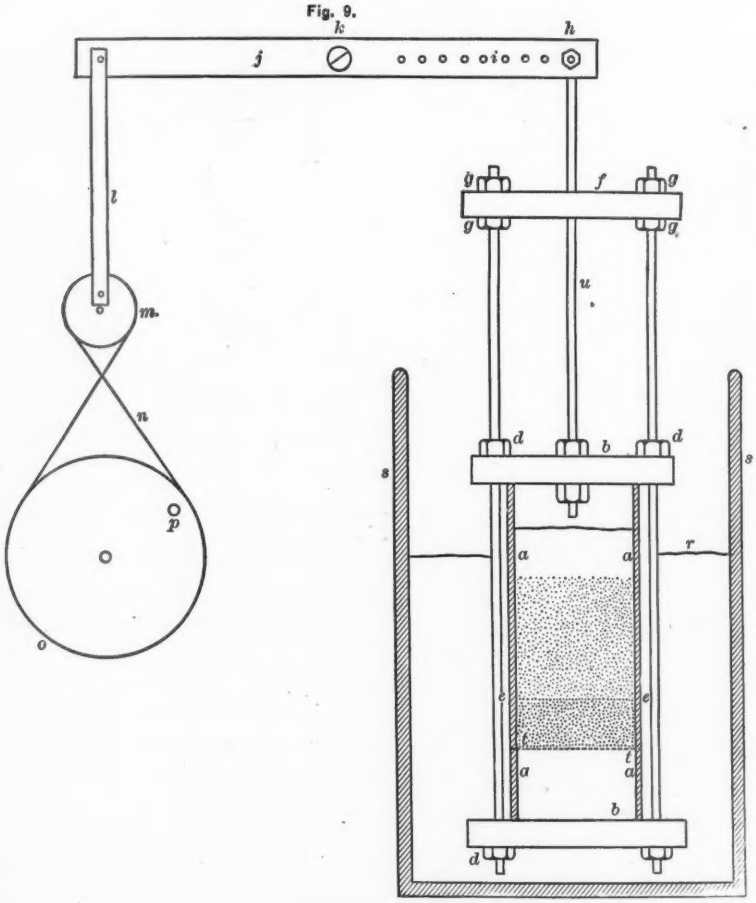
Two tests were made with the pulsion-jig, one upon galena and one upon sphalerite, each paired with quartz.

For convenience, when in use the sieve was removed. This permitted the products to be drawn off by the bulb in series exactly as they were in the pointed tube test, and the bulbs so drawn off were sized, and the different little hills were laid out and photographed as before (Plates XIV and XV).

The ratio for three columns of hills, computed by the method adopted for the pointed tube, yielded for the two minerals treated, namely, galena and sphalerite, the figures shown in Table XXXIX.

If now we compare these ratios of Table XXXIX with those obtained by the pointed tube (Table XXXVII), we see that nothing whatever has been gained by adding acceleration to interstitial cur-

Fig. 9.



MOVABLE SIEVE-JIG.

rents. But since acceleration must logically produce some result, there should be some explanation of its apparent failure here. It is quite possible that this is a case of "parallelism," just as if two cells of a battery be placed side by side in multiple arc nothing is gained

TABLE XXXVIII.

GALENA AND QUARTZ HILLS OF PLATE IIb, TESTED WITH THE FREE-FALLING TUBE (FIGURE 6) FOR FALL VELOCITIES.

Sieve-Mesh.	Series of Bulbs Drawn from Pointed Tube.									
	1	2	3	4	5	6	7	8	9	10
	Velocity in Inches per Second (Mean of Four Determinations).									
12. .	15 36	14.22	.....	6.62	6.192	6.047	.....	.....	.....	.....
14. .	13.24	13 01	.....	6.295	6.192	5.687	4.291	.....	.....	.....
16. .	13.24	12.39	.....	5.446	5.774	5.224	4 266	.....	.....	.....
18. .	11.46	11.81	96	5.333	5.019	4.80	4.412	.....	.....	.....
20. .	11.13	10.97	8 257	.....	4.544	4.266	4.062	.....	.....	.....
24. .	10.52	10.24	9.72	.....	4.196	4.00	3.8975	3.413	.....	.....
30. .	9.48	9.142	7.603	.....	.....	3.821	3.412	.....	.....	.....
40. .	6.678	7.110	6 562	5.731	.....	.....	2.898	2.666	.....	.....
50. .	.....	6.399	5.774	.....	4.314	.....	2.377	2.151	1.969	.....
60. .	.....	.....	4.86	4 86	3.692	3.443	1.882	1.714	1 506	.....
80. .	.....	.....	4.314	.....	3.491	3.011	.....	1.326	1.196	.....
100. .	.....	.....	.....	3.00	3.00	2.493	2.121	1.046	0.8438	.....
120. .	.....	.....	.....	.....	2.603	2.40	2.453	.....	0 5253	.....
140. .	.....	.....	.....	.....	.....	1.846	1.740	.....	0.4757	.....
Slimes.	.....	.....	.....	.....	.....	1.691	.....	.....	.....	.....

in volts, or as two horses harnessed side by side are no faster than one horse.

Tables XL and XLI give the weights of the hills in three columns each of Plates XIV and XV, from which the computations in Table XXXIX were made.

IV. SUCTION.

This law of jigging has not received the attention which it deserves. Munroe says of it that suction appears to be necessary for jigging through a bed. Hoppe says that suction is very necessary to jigging, and that he has in progress an investigation of it.

In order to test the limits of the law of suction I have designed

TABLE XXXIX.

ACCELERATION FACTORS, OR MULTIPLIERS FOR OBTAINING THE DIAMETER OF THE PARTICLE OF QUARTZ WHICH, IN THE PULSION-JIG, WILL BE IN EQUILIBRIUM WITH THE MINERAL SPECIFIED.

QUARTZ WITH	Ratio of Average Quartz Diameter to Average Mineral Diameter.		
	Column 5.	Column 6.	Column 7.
Galena	7.161	6.103	5.074
Sphalerite	2.091	2.148	1.972

TABLE XL.

QUARTZ AND GALENA BY PULSION-JIG (Plate XIV).

SIEVE-MESH.	BULB NO. 5.		BULB NO. 6.		BULB NO. 7.	
	Galena, Grams.	Quartz, Grams.	Galena, Grams.	Quartz, Grams.	Galena, Grams.	Quartz, Grams.
12 . . .	.....	14.1593	.....	4.7280	.....	0.0512
14 . . .	.....	6.9501	.....	5.5411	.....	0.5227
16 . . .	.....	2.7127	.....	2.6621	.....	0.4019
18 . . .	.....	3.6445	.....	8.7326	.....	3.1527
20 . . .	.....	0.5471	.....	2.2216	.....	2.0265
24 . . .	.....	0.2946	.....	4.1468	.....	5.3038
30 . . .	0.0023	0.0430	.....	3.1682	.....	11.0832
40 . . .	0.0378	0.0020	0.0161	0.3059	.....	4.6484
50 . . .	0.1887	.....	0.0189	0.0189	0.0520	1.6818
60 . . .	1.3844	.....	0.1124	.....	0.0136	0.2582
80 . . .	11.4166	.....	2.5483	.....	0.3189	0.0354
100 . . .	8.7252	.....	9.9107	.....	5.9146	.....
120 . . .	0.3900	.....	1.1889	.....	2.2753	.....
140 . . .	0.0487	.....	0.3558	.....	0.9300	.....
Slimes . .	0.0382	.....	0.5548	.....	3.2828	.....
Total . .	22.2319	28.3533	14.7059	31.5252	12.7872	29.1658

TABLE XLI.

QUARTZ AND SPHALERITE BY PULSION-JIG (Plate XV).

SIEVE-MESH.	BULB No. 5.		BULB No. 6.		BULB No. 7.	
	Sphalerite, Grams.	Quartz, Grams.	Sphalerite, Grams.	Quartz, Grams.	Sphalerite, Grams.	Quartz, Grams.
12 . . .	.....	5.1771	.....	0.9170	.....	0 0533
14 . . .	.....	7.3021	.....	2.7287	.....	0.2564
16 . . .	.....	2.5224	.....	2.0799	.....	0.3592
18 . . .	0.2887	5.4855	0.0809	8.0078	.....	2.8745
20 . . .	0.5432	0.8149	0.0246	2.4345	.....	1.9888
24 . . .	2.7250	0.9083	0.8308	3.3234	0.0594	5.8787
30 . . .	9.9139	0.2023	4 2891	4.2891	0.4980	9.4620
40 . . .	3.5496	.....	6.8335	0.3597	3.5382	3.5382
50 . . .	0.7999	.....	3.5911	.....	5.9406	0.6601
60 . . .	0.1484	.....	1 3368	.....	4.0482	.....
80 . . .	.....	.....	0.3341	.....	1.8364	.....
100 . . .	.....	.....	.....	.....	0.0969	.....
120 . . .	....	.....	.....	.....	.....	.....
140 . . .	.....	.....	.....	.....	.....	.....
Slimes . .	.....	.....	.....	.....	.....	.....
Total . .	17.9687	22.4126	17.3409	24.1401	16.0177	25.0712

a little movable sieve-jig, shown in Figure 9, which gives a very perfect jigging action. It consists of a glass tube (*a*, *a*, *a*, *a*) 5 inches long and $1\frac{1}{4}$ inches in bore, which is cut at *t*, *t*, into two parts, 4 inches and 1 inch long respectively — the 4 inches being above the sieve; a disk of sieve-cloth (*t*, *t*) is inserted between them; the parts are held together by the wooden bars (*b*, *b*) and the bolts (*e*, *e*), with nuts (*d*, *d*). Power is transmitted through the rod (*hu*), the beam (*j*) oscillating upon a pivot (*k*), a connecting rod (*l*), a small pulley (*m*) with crank-pin, a belt (*n*), and a large pulley (*o*) driven by a crank (*p*). The cross-bar (*f*) and the lock-nuts (*g*, *g*) are used simply to stiffen the rod (*u*). The jig is suspended in a glass jar (*s*) with water-level at *r*.

By turning the crank (*p*) an oscillating motion up and down is given to *l*, received by *u*, and transmitted to the jig-sieve (*t*, *t*). The amount of oscillation may be controlled by connecting *u* with *j* by means of any of the holes (*i*). The smallest oscillation was $\frac{1}{8}$ inch, the largest $\frac{5}{8}$ inch. The latter was preferred for the tests.

The effects of pulsion and suction were studied in three different combinations, namely, full pulsion with much, with little, and with no suction.

1. *Full Pulsion with Much Suction.*—When the jig (Figure 9) is run with the glass tube elevated $1\frac{1}{2}$ inches above the surface of the water at the lowest point of its stroke, the jig operates during the first few pulsations as a lift-pump, elevating the surface of the water within its tube until the inside water level is perhaps 1 inch above the outside level, the sand particles acting like so many little valves. Thus it reaches equilibrium, and from this time on the suction due to the downward rush of water must be equal to the pulsion due to the upward rush of water. The bed of this jig is tight and only slightly mobile. The strong suction compacts it more or less. Mobility may be restored by using a long stroke.

2. *Full Pulsion with Little Suction.* — When the jig is run with the glass tube inundated to a depth of $\frac{7}{8}$ inch below the surface of the water at the lowest point in its stroke, then, during the downward movement of the sieve, a full pulsion movement is given to the water as it passes up through the sieve, and the sand settles through it. But on the upward movement the sand settles in the sieve, and comparatively little suction results from the inertia of the water. The reason is that there is a free discharge of the water at the top of the glass tube. Here we have full pulsion with little suction. The bed of this jig is loose and very mobile. There is not enough suction to compact it. A shorter stroke here suffices for mobility.

3. *Full Pulsion with No Suction.* When the pulsion-jig (Figure 8) is used upon mixed sands, it matters not whether we revolve the cock rapidly, giving rapid, small pulsations with short intervals of repose, or more slowly, giving fewer and stronger pulsations with longer periods of repose, the result is the same. The sands are treated by pulsion without suction. The bed of this jig is extremely loose and mobile, there being no suction to compact it.

In all the tests upon jigging now to be described, unless otherwise stated, the stroke of the jig was $\frac{5}{8}$ inch; the layer of quartz was 2 inches thick; the layer of the added mineral to be separated from the quartz was $\frac{3}{16}$ inch deep, and placed on top of the quartz. When the jig is said to be "elevated," the top of the glass is $1\frac{1}{2}$ inches above the water at the lowest point of the stroke; and when the jig is said to be "inundated," the top of the tube is $\frac{7}{8}$ inch below the surface of the water at the lowest point in the stroke. A 16-mesh sieve was used in the jig throughout the tests.

The first series of tests was made with quartz and galena to note the behavior of different sizes of galena with a single standard size of quartz. For this purpose the two minerals were jigged together as follows:

Quartz, in all cases, through 10 and on 12 mesh; average diameter, 0.0725 inch.

GALENA.	Tests 1, 2, and 3.	Tests 4, 5, and 6.	Tests 7, 8, and 9.	Tests 10, 11, and 12.	Tests 13, 14, and 15.	Tests 16, 17, and 18.
Through (meshes per inch) . . .	10	16	24	30	60	140
On (meshes per inch)	12	18	30	40	80	....
Average diameter, inches. . . .	0.0725	0.0429	0.0262	0.00195	0.0095	0.0042

Each pair was treated with much suction, with little suction, and with no suction.

The results are given in Table XLII; and the following conclusions as to the behavior of quartz and galena are indicated:

Light suction is more rapid than heavy suction (tests 1 and 2); no suction is more rapid than light suction (tests 2 and 3). Where the galena is fine, much suction is rapid; but no suction is also rapid (tests 10, 11, and 12) until 60 to 80 mesh is reached (test 15), where galena is in equilibrium with the quartz. With heavy suction there is an interesting maximum reached at .0262 diameter galena (test 7). Here the galena is too fine for equal-settling particles to help it much, and it is too coarse to be sucked down in the interstices of the quartz;

TABLE XLII.— Jig Tests of Quartz and Galena.

Test 1.
Quartz of diameter, .0725.
Galena diameter, .0725.
Jig elevated, much suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
31	199	95	Layer on sieve.
40	257	100	Layer on sieve.
60	385	...	.....

Test 2.
Quartz of diameter, .0725.
Galena diameter, .0725.
Jig inundated, little suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
25	153	100	Layer on sieve.
60	368	...	.....
Repeated.			
15	95	100	On sieve.
60	381	...	.....

Test 3.
Quartz of diameter, .0725.
Galena diameter, .0725.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
45	237	....	100	Down.
60	317	996 cc.	...	Too little water, quite sluggish.
Repeated wi h more water.				
4	18	....	100	Down on sieve.
60	275	1319 cc.	...	Very active.

Test 4.
Quartz of diameter, .0725.
Galena diameter, .0429.
Jig elevated, much suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
35	235	0	On sieve.
45	302	100	On sieve.
60	403	...	.....

Test 5.
Quartz of diameter, .0725.
Galena diameter, .0429.
Jig inundated, little suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
50	320	0	On sieve.
55	352	50	On sieve.
60	384	100	On sieve.

Test 6.
Quartz of diameter, .0725.
Galena diameter, .0429.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
5	25	....	95	Down on sieve.
10	50	....	100	Down on sieve.
60	301	1231 cc.	...	.....

Test 7.
Quartz of diameter, .0725.
Galena diameter, .0262.
Jig elevated, much suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
40	222	0	Through sieve.
45	249	80	Through sieve.
75	416	92	Through sieve, worked very slowly.
135	748	98	Through sieve, worked very slowly.

Test 8.
Quartz of diameter, .0725.
Galena diameter, .0262.
Jig inundated, little suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
15	76	90	Through sieve.
30	153	98	Through sieve.
60	306	100	Through sieve.

Test 9.
Quartz of diameter, .0725.
Galena diameter, .0262.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
10	58	....	98	Down through sieve.
60	346	999 cc.	...	.....
Repeated.				
10	62	....	98	Down through sieve.
60	371	1235 cc.	...	.....

TABLE XLII. — *Continued.*

Test 10.

Quartz of diameter, .0725.
Galena diameter, .0195.
Jig elevated, much suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
30	168	0	Through sieve.
35	196	80	Through sieve.
60	337	99	Through sieve.

Test 11.

Quartz of diameter, .0725.
Galena diameter, .0195.
Jig inundated, little suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
20	105	0	Through sieve.
30	157	80	Through sieve.
40	210	99	Through sieve.
45	236	100	Through sieve.
60	315	...	.....

Test 12.

Quartz of diameter, .0725.
Galena diameter, .0195.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
15	92	....	75	Down.
60	368	999 cc.	95	Down.

Test 13.

Quartz of diameter, .0725.
Galena diameter, .0095.
Jig elevated, much suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
5	31	0	Through sieve.
15	95	80	Through sieve.
30	190	100	Through sieve.
60	380	...	.....

Test 14.

Quartz of diameter, .0725.
Galena diameter, .0095.
Jig inundated, little suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
5	25	0	Through sieve.
15	76	80	Through sieve.
30	153	100	Through sieve.
60	306	...	.....

Test 15.

Quartz of diameter, .0725.
Galena diameter, .0095.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
60	368	1231 cc.	60	Through.

A portion of this went through in a body. The rest stayed up and appeared perfectly balanced among the quartz in equilibrium.

Test 16.

Quartz of diameter, .0725.
Galena diameter, .0042.
Jig elevated.

Time, Sec.	Pulsations.	Notes.
15	86	All through, except galena-stained water.
60	346	.....

Test 17.

Quartz of diameter, .0725.
Galena diameter, .0042.
Jig inundated.

Time, Sec.	Pulsations.	Notes.
5	30	All the coarser part through the sieve. The finer sizes were floating just above the quartz layer.
60	354	.....

Test 18.

Quartz of diameter, .0725.
Galena diameter, .0042.
Pulsion-jig.

This was not tried, as the galena would certainly have floated on top of the quartz.

hence its slow action. Compare it with .0195 diameter galena (test 10), which is small enough to be sucked down in the interstices. Here heavy suction brings quite a rapid separation.

The second series of tests was made upon quartz and sphalerite (blende) put together in pairs as in the experiments just described. The diameters were the same as those given above for the similar tests with galena.

The results are given in Table XLIII, and the following conclusions as to the behavior of quartz and sphalerite are indicated.

When the quartz and sphalerite are of the same size, light suction is far more rapid in its action than heavy suction (tests 19 and 20), and no suction is most rapid of all (test 21). As the discrepancy in size increases, heavy suction gains slightly and light suction loses ground slightly (tests 22 and 23, also 25 and 26). No suction breaks down entirely in test 27; equilibrium is here reached. When, however, .0195 diameter sphalerite is reached, there comes a complete reversal; the heavy suction gives a rapid result (test 28), and the light suction is quite slow (test 29). No suction was not tried because the upward current in the previous experiment was too much for a larger sized sphalerite. From this down the heavy suction is rapid (tests 31 and 34), while the light suction grows weaker in each number of the series towards the lower end (tests 29, 32, and 35), where the rate of jigging had to be diminished in order to lessen the upward current before the sphalerite would go through the sieve at all (see test 32 for example).

We seem here, to a more marked degree than with galena, to have the measure of the size of the interstices in the quartz of 10 to 12 mesh or .0683 inch diameter, for the sphalerite through 24 on 30-mesh (= .0262 diameter) is settled only with extreme difficulty according to the laws of equal-settling particles and interstitial currents, while sphalerite of 30 to 40 mesh (= .0195 diameter) is drawn down with great rapidity by suction. We may assume, therefore, that this size is the coarsest that can move freely in the interstices of quartz of 10 to 12 mesh size.

The third series of tests was made upon quartz in large grains, with quartz in small grains, to determine the effects of suction and pulsion. For this purpose the two kinds were jigged by pairs, as follows (the results are given in Table XLIV).

Quartz passing through 10-mesh and resting on 12-mesh sieve (average diameter, 0.0725 inch) was jigged with quartz of the following sizes:

Test No.	Through Mesh.	On Mesh.	Diameter in Inches.
37, 38	24	30	0.0262
39, 40	30	40	0.0195
41, 42	60	80	0.0095
43, 44	140	....	0.0042

We conclude, with regard to quartz of different sizes, that strong suction can draw down small grains of quartz through the interstices between large grains of quartz (tests 39, 41, and 43), and, if there is no intercepting heavy mineral layer below, these small particles will go through the sieve. Light suction, with excess of pulsion, cannot draw small quartz down (tests 40 and 42) so long as the jig is really working. When, however, the pulsions are so slow as not to move the coarse quartz (test 42), then suction equals pulsion and sifting takes place. Strong pulsion with no suction cannot draw down fine quartz through the interstices of 10 to 12 mesh quartz under any circumstances. The quartz will always be graded by size — the coarser below, the finer above, as in the pointed tube.

The fourth series of tests comprised the jigging of mixed sizes upon a number of minerals ranging from copper at the heavy end of the series to anthracite at the light end. Each mineral was mixed with quartz in approximately equal quantity by volume, and the sizes in all cases were from 10-mesh to dust. The pairs were composed of quartz with copper, galena, antimony, arsenopyrite, chalcocite, magnetite, pyrrhotite, sphalerite, epidote, and anthracite, respectively. The results are given in Table XLV. To aid in interpreting these results, the skimmings or tailings from each of the tests were sifted upon the nest of sieves; each size was spread out upon a sheet of paper, and the quantity of the heavy mineral in it was estimated by the eye, as per cent. by volume or number of grains in one hundred grains. The results of this sifting and valuing process are given in Tables XLVI, XLVII, and XLVIII.

As a means of comparing quickly the final results of these jig-

TABLE XLIII.—JIG TESTS OF QUARTZ AND SPHALERITE.

Test 19.

Quartz of diameter, .0725.
Sphalerite (blende) diameter, .0725.
Jig elevated, heavy suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	310	0	On sieve, average $\frac{1}{4}$ down.
120	611	0	On sieve, average $\frac{4}{10}$ down.
180	908	5	On sieve, average $\frac{6}{10}$ down.
240	1207	10	On sieve, average $\frac{7.5}{10.5}$ down.
300	1513	50	On sieve, rest scattering.
360	1819	80	On sieve, rest scattering.
420	2129	96	On sieve, rest scattering.

Test 20.

Quartz of diameter, .0725.
Sphalerite (blende) diameter, .0725.
Jig inundated, light suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	306	99	On sieve, last few grains hard to separate.

Test 21.

Quartz of diameter, .0725.
Sphalerite diameter, .0725.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
15	37	.....	95	On sieve.
60	147	770 cc.	98	On sieve, last end hard to clean.

Test 22.

Quartz of diameter, .0725.
Sphalerite diameter, .0429.
Jig elevated, heavy suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	270	0	Average, $\frac{1}{4}$ down.
120	558	2	Through sieve.
180	833	30	Through sieve.
240	1117	75	Through sieve.
300	1401	90	Through sieve.
360	1676	95	Through sieve.

Test 23.

Quartz of diameter, .0725.
Sphalerite diameter, .0429.
Jig inundated, light suction.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	284	50	On or through sieve.
120	563	90	On or through sieve.
180	838	99	On or through sieve.

Test 24.

Quartz of diameter, .0725.
Sphalerite diameter, .0429.
Pulsion-jig, no suction.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
62	230	.....	90	On or through sieve.
Repeated.				
60	202	695 cc.	95	Much better, but last grains hard to settle.

TABLE XLIII. — *Continued.*

Test 25.

Quartz of diameter, .0725.
Sphalerite diameter, .0262.
Jig elevated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	266	25	Sifted.
120	558	50	Sifted.
180	850	85	Sifted.
240	1138	90	Sifted.
300	1422	92	Sifted.
360	1759	95	Sifted. Increased speed seemed to help a little here.

Test 26.

Quartz of diameter, .0725.
Sphalerite diameter, .0262.
Jig inundated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	288	70	Sifted.
120	567	95	Sifted.
180	846	100	Sifted.

Test 27.

Quartz of diameter, .0725.
Sphalerite diameter, .0262.
Pulsion-jig.

Time, Sec.	Pulsations.	Water.	Per cent.	Notes.
60	176	690 cc.	0	Average, $\frac{1}{3}$ from top.
120	358	.....	0	Average, $\frac{1}{4}$ from top and at equilibrium.
	Tried slower pulsations on the continuation of the test.			
180	406	.....	0	Average, $\frac{1}{8}$ down, decided gain.
	Water cut down to 545 cc. per minute.			
240	451	.....	..	.....
300	496	.....	50	Down, much better but very imperfect operation.

Test 28.

Quartz of diameter, .0725.
Sphalerite diameter, .0195.
Jig elevated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	297	95	Sifted.
120	603	100	Sifted, worked very rapidly.

Test 29.

Quartz of diameter, .0725.
Sphalerite diameter, .0195.
Jig inundated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	319	65	Sifted.
120	611	90	Sifted.
180	877	92	Sifted.
240	1134	95	Sifted.
300	1382	98	Sifted.

Test 30.

The pulsion-jig broke down on sphalerite diameter, .0262. It therefore was not tried on these lower sizes.

TABLE XLIII. — *Continued.*

Test 31.

Quartz of diameter, .0725.
Sphalerite diameter, .0095.
Jig elevated.

Time, Sec.	Pulsations.	Per cent.	Notes.
45	208	99	Sifted very rapidly.

Test 32.

Quartz of diameter, .0725.
Sphalerite diameter, .0095.
Jig inundated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	319	75	Sifted.
120	642	80	Sifted.
180	930	82	Sifted.
240	1307	82	Equilibrium sphalerite collected at top.
300	1529	90	Slow speed caused sifting to start again fairly well.
360	1729	97	.....

Test 33.

No test.

Test 34.

Quartz of diameter, .0725.
Sphalerite diameter, .0042.
Jig elevated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	288	99	All sifted, except a little muddy water. Time probably much too large.

Test 35.

Quartz of diameter, .0725.
Sphalerite diameter, .0042.
Jig inundated.

Time, Sec.	Pulsations.	Per cent.	Notes.
20	62	0	All floated up on quartz.
Repeated.			
30	84	99	Sifted. Pulsations too slow to pump the quartz, hence sifted.

Test 36.

No test.

ging tests, the phrase "5 per cent. in the tails reached up to . . . . mesh" is used. The figures inserted in the blank are taken from Tables XLVI, XLVII, and XLVIII, and will be seen to give a quick and fairly good summing up of the tests.

The conclusions as to the jigging of mixed sizes are as follows:

In the elevated (heavy suction) tests, the tailings retrograde rapidly from copper towards arsenopyrite. From arsenopyrite on they retrograde but little. (See Table XLVI.)

Again, in the inundated (light suction) tests, beginning with copper, the quality of the tailings of each mineral is much poorer than that of the mineral next preceding it, until arsenopyrite is reached. Here again there is a change — the tailings of arsenopyrite are much worse than those of antimony, and but little better than those of its lighter neighbors to the right.

For testing the pulsion-jig, the corresponding values were obtained by assuming that the pulsion-jig and the pointed tube have practically the same effect. This has been proved at two ends of the series (compare Plate XIV with Plate 11*b*, and Plate XV with Plate X; also, the tables of figures which correspond).

On this assumption, we take, for example, Plate 11*b*. Clearly bulbs Nos. 1, 2, and 3 form the heads of jigging, and bulbs Nos. 4, 5, 6, 7, 8, 9, and 10 form the tails. We estimate the percentage of galena in these different sizes of the tailings. There is no galena in 12, 14, 16, 18, 20, and 24-mesh grains. From 30-mesh down my estimate is given in Table XLVIII, together with estimates made in like manner on Plates I to XII inclusive.

Once more arsenopyrite appears as the turning point in the series, the tailings of the successive minerals rapidly retrograding in the series until arsenopyrite is reached, while the tailings of the minerals to the right of arsenopyrite are but little worse than those of that mineral.

Quartz being the heavier mineral of quartz and anthracite, it is much too good to be in the company it is. The ratio between quartz and anthracite is nearly as great as between quartz and antimony.

The results of this series prove conclusively that strong suction is more efficient for jigging mixed sizes than weak suction (compare Nos. 45 and 46, 48 and 49, etc.); and, again, that weak suction is more efficient than no suction (compare Nos. 46 and 47, 49 and 50, etc.).

These tests show, also, that in jigging mixed sizes of a series of

TABLE XLIV. — Jig Tests of Coarser and Finer Quartz.

Test 37.

Quartz of diameter, .0725.
Quartz diameter, .0262.
Jig elevated.

Time, Sec.	Pulsations.	Per cent.	Notes.
60	265	0	Quartz all on top.
120	628	0	Quartz all on top.
180	1177	0	A little down $\frac{1}{4}$ inch.
240	1952	0	A little down 1 inch.

The great variation in speed effected little.

Test 38.

Quartz of diameter, .0725.
Quartz diameter, .0262.
Jig inundated.

Not tried.

Test 39.

Quartz of diameter, .0725.
Quartz diameter, .0195.
Jig elevated, $\frac{3}{8}$-inch stroke.

Time, Sec.	Pulsations.	Notes.
60	292	No sifting, all fine quartz on top.
120	744	Rapid jigging, top layer disappeared, sifting began.
180	988	Slow jigging, sent the grains back up to the top.

Test 40.

Quartz of diameter, .0725.
Quartz diameter, .0195.
Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	496	Fast, sent all fine quartz to top.
120	775	Slower, sent all fine quartz to top.
180	997	Slower, sent all fine quartz to top.
240	1179	Slower, sent all fine quartz to top.

Test 41.

Quartz of diameter, .0725.
Quartz diameter, .0095.
Jig elevated.

Time, Sec.	Pulsations.	Notes.
5	22	Began sifting.
60	266	Sifting freely.
120	536	All sifted.

Test 42.

Quartz of diameter, .0725.
Quartz diameter, .0095.
Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	399	Fast jigging, all fine quartz on top.
120	696	Slower, all fine quartz on top.
180	935	Slower, all fine quartz on top.
240	1143	Slower, 15 per cent. sifted, no pumping motion.
300	1289	Slower, 30 per cent. sifted, no pumping motion, fine quartz on top.

Test 43.

Quartz of diameter, .0725.
Quartz diameter, .0042.
Jig elevated.

Time, Sec.	Pulsations.	Notes.
18	88	Fine quartz all sifted, except a little muddy water.

Test 44.

Quartz of diameter, .0725.
Quartz diameter, .0042.
Jig inundated.

Time, Sec.	Pulsations.	Notes.
19	49	Coarsest of fine quartz sifted, finest lifted.

TABLE XLV. — Jig Tests of Mixed Sizes.

Test 45.

Quartz and Copper through 10-mesh.
Jig elevated, $\frac{5}{8}$-inch stroke.

Time, Sec.	Pulsations.	Notes.
60	323	Some 30-mesh copper still in quartz.
120	633	Practically clean.
180	948	No change.

Five per cent. in the tails reached up to 120-mesh sieve.

Test 46.

Quartz and Copper through 10-mesh.
Jig inundated, $\frac{5}{8}$-inch stroke.

Time, Sec.	Pulsations	Notes.
60	319	20-mesh copper in quartz.
120	647	40-mesh copper in quartz.
195	1055	A little copper still in quartz.
255	1370	No better than last.

Five per cent. in the tails reached up to 80-mesh.

Test 47.

Quartz and Copper through 10-mesh.
Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 30-mesh.

Test 48.

Quartz and Galena through 10-mesh.
Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	354	Some 40-mesh still showing.
120	669	Clean to the eye.
180	979	No change.

Five per cent. in the tails reached only to fines.

Test 49.

Quartz and Galena through 10-mesh.
Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	310	Some 40-mesh galena still showing in quartz, a dark layer of fines on top.
120	629	Some 50-mesh galena still showing in quartz, a dark layer of fines on top.
180	935	Some 60-mesh galena still showing in quartz, a dark layer of fines on top.
240	1241	Some 80-mesh galena still showing in quartz, a dark layer of fines on top.
300	1560	Some 80-mesh galena still showing in quartz, a dark layer of fines on top.
360	1883	Some 80-mesh galena still showing in quartz, a dark layer of fines on top.

Five per cent. in the tails reached up to 60-mesh.

Test 50.

Quartz and Galena through 10-mesh.
Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 50-mesh.

TABLE XLV. — *Continued.*

Test 51.

Quartz and Antimony through 10-mesh. Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	319	80-mesh antimony showing in quartz.
120	656	Quartz practically clean.
180	984	No change.

Five per cent. in the tails reached only to fines.

Test 52.

Quartz and Antimony through 10-mesh. Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	315	30-mesh antimony in the quartz, a dark layer of fines on top.
120	652	40-mesh antimony in the quartz, a dark layer of fines on top.
180	962	50-mesh antimony in the quartz, a dark layer of fines on top.
240	1272	50-mesh, no better than last.
300	1573	50-mesh, no better than last.

Five per cent. in the tails reached up to 50-mesh.

Test 53.

Quartz and Antimony through 10-mesh. Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 30-mesh.

Test 54.

Quartz and Arsenopyrite through 10-mesh. Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	350	A little 60-mesh arsenopyrite showing in quartz.
120	682	Clean to the eye.
180	905	Clean to the eye.

Five per cent. in the tails reached 100-mesh.

Test 55.

Quartz and Arsenopyrite through 10-mesh. Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	315	30-mesh arsenopyrite, showing in quartz a dark layer of fines on top.
120	638	50-mesh arsenopyrite, showing in quartz a dark layer of fines on top.
180	975	60-mesh arsenopyrite, showing in quartz a dark layer of fines on top.
240	1316	60-mesh no better, showing a dark layer of fines on top.
300	1666	60-mesh no better, showing a dark layer of fines on top.

Five per cent. in the tails reached up to 40-mesh.

Test 56.

Quartz and Arsenopyrite through 10-mesh. Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 14-mesh.

TABLE XLV. — *Continued.*

Test 57.

Quartz and Chalcocite through 10-mesh. Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	275	50-mesh chalcocite showing in quartz.
120	594	60-mesh chalcocite showing in quartz.
180	926	80-mesh chalcocite showing in quartz.
240	1263	Very little improvement.
300	1586	No better.

Five per cent. in the tails reached up to 60-mesh.

Test 58.

Quartz and Chalcocite through 10-mesh. Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	323	40-mesh chalcocite in the quartz, a dark layer of fines on top.
120	664	50-mesh chalcocite in the quartz, a dark layer of fines on top.
180	992	60-mesh chalcocite in the quartz, a dark layer of fines on top.
240	1311	Little or no better, a dark layer of fines on top.
300	1626	Little or no better, a dark layer of fines on top.
360	1958	No better.

Five per cent. in the tails reached up to 40-mesh.

Test 59.

Quartz and Chalcocite through 10-mesh. Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 12-mesh.

Test 60.

Quartz and Magnetite through 10-mesh. Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	319	20-mesh magnetite in quartz.
120	620	Less 20-mesh magnetite in quartz.
180	961	Less 20-mesh magnetite in quartz.
240	1302	Less 20-mesh magnetite in quartz.
300	1639	No better.

Five per cent. in the tails reached only fines.

Test 61.

Quartz and Magnetite through 10-mesh. Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	346	18-mesh magnetite in the quartz, a slight dark layer of fines on top.
120	674	20-mesh magnetite in the quartz, a slight dark layer of fines on top.
180	1011	20-mesh magnetite in the quartz, a slight dark layer of fines on top.
240	1321	24-mesh magnetite in the quartz, a slight dark layer of fines on top.
300	1640	No better.

Five per cent. in the tails reached 24-mesh.

Test 62.

Quartz and Magnetite through 10-mesh. Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached 14-mesh.

TABLE XLV. — *Continued.*

Test 63.

Quartz and Pyrrhotite through 10-mesh. Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	337	30-mesh pyrrhotite in the quartz.
120	683	30-mesh pyrrhotite in the quartz, better than last.
180	998	30-mesh pyrrhotite in the quartz, better than last.
240	1317	30-mesh pyrrhotite in the quartz, better than last.
300	1632	No better.

Five per cent. in the tails reached up to 60-mesh.

Test 64.

Quartz and Pyrrhotite through 10-mesh. Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	293	30-mesh pyrrhotite in the quartz, a dark layer of fines on top.
120	616	30-mesh, better.
180	842	30-mesh, better.
240	1112	30-mesh, better.
300	1458	A little better, dark layer most gone.
360	1773	No better.

Five per cent. in the tails reached up to 30-mesh.

Test 65.

Quartz and Pyrrhotite through 10-mesh. Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 12-mesh.

Test 66.

Quartz and Sphalerite through 10-mesh. Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	328	20-mesh sphalerite in the quartz.
135	722	30-mesh sphalerite in the quartz.
195	1041	40-mesh sphalerite in the quartz.
270	1440	50-mesh sphalerite in the quartz.
330	1755	A few scales still sifting.
390	2061	A few scales still sifting.
450	2384	Practically clean.

Five per cent. in the tails reached up to 120-mesh.

Test 67.

Quartz and Sphalerite through 10-mesh. Jig inundated.

Time Sec.	Pulsations.	Notes.
60	310	18-mesh sphalerite in quartz, thick dark layer of fines on top.
120	625	20-mesh sphalerite in quartz.
180	904	20-mesh, gaining a little.
240	1210	30-mesh, gaining a little.
300	1533	30-mesh, gaining a little.
360	1870	30-mesh, gaining a little.
420	2202	30-mesh, gaining a little.
540	2849	30-mesh sifting ceased, thin dark layer of fines on top.

Five per cent. in the tails reached up to 30-mesh.

Test 68.

Quartz and Sphalerite through 10-mesh. Pointed tube, *i.e.*, pulsion-jig.

Five per cent. in the tails reached up to 12-mesh.

TABLE XLV. — *Continued.*

Test 69.

Quartz and Epidote through 10-mesh.
Jig elevated, much suction.

Time, Sec.	Pulsations.	Notes.
60	337	Sifting rapidly, but some 14-mesh epidote in quartz.
120	660	Bed packed.
180	997	Still sifting a little.
240	1329	Still sifting a little.
300	1639	No better. Much quartz sifted.

Five per cent. in the tails reached up to 16-mesh.

Test 70.

Quartz and Epidote through 10-mesh.
Jig inundated, little suction.

Time, Sec.	Pulsations.	Notes.
60	283	Much 16-mesh in quartz, a layer of fine epidote on top.
120	595	Much 16-mesh in quartz, a layer of fine epidote on top.
180	890	No better.
240	1200	No better.
300	1488	No better. A little quartz sifted.

Five per cent. in the tails reached up to 16-mesh.

Test 71.

Quartz and Epidote through 10-mesh.
Pulsion-jig, no suction.

Five per cent. in the tails reached up to 12-mesh.

Test 72.

Quartz and Anthracite through 10-mesh.
Jig elevated.

Time, Sec.	Pulsations.	Notes.
60	392	Some 16-mesh quartz in the anthracite.
120	602	Some 20-mesh.
195	970	Practically clean.

Five per cent. of quartz in the anthracite reached up to 30-mesh.

Test 73.

Quartz and Anthracite through 10-mesh.
Jig inundated.

Time, Sec.	Pulsations.	Notes.
60	275	Some 16-mesh quartz in the anthracite.
120	576	A few 16-mesh left.
195	913	Some 40-mesh.
255	1196	A little better.
315	1484	A little better.
375	1781	Some 60-mesh.
435	2118	Practically clean to the eye.

Five per cent. of quartz in the anthracite reached up to 60-mesh.

Test 74.

Quartz and Anthracite through 10-mesh.
Pulsion-jig.

Five per cent. of quartz in the anthracite reached up to 24-mesh.

TABLE XLVI.

PERCENTAGE OF HEAVY MINERAL IN TAILS, IN TESTS WITH JIG ELEVATED. MUCH SUCTION.

SIEVE-MESH.	Copper.	Galena.	Antimony.	Arsenopyrite.	Chalcocite.	Magnetite.	Pyrrhotite.	Sphalerite.	Epidote.	Quartz in Anthracite.
12	0	0	0	0	0	0	0	0	2	0.1
14	0	0	0	0	0	2	0	0	3	0.5
16	0	0	0	0.5	0	1.5	2	0	8	0.7
18	0	0	0	0	0	3	2	2	20	1.5
20	0	0	0	0	0	4	1	1.5	25	1.5
24	0	0	0	1	0	3	2	2	25	2
30	0	0	1	2	1	3	4	3	25	5
40	0.1	0.1	1	2	2	3	4	3	30	5
50	0.1	0.1	1	2	3	3	4	3	45	8
60	0.5	0.1	0.5	3	5	2	5	2	45	10
80	0.5	0.1	0.5	3	5	3	6	3	40	15
100	3	1	1	5	6	2	8	4	30	20
120	5	1	2	5	5	3	8	5	25	35
140	7	1	2	3	5	3	8	6	20	35
Slimes	5	7	10	8	10	5	20	10	20	50

minerals we have found arsenopyrite to be the middle cone of the three (see Figure 7), the turning point in the set, where the heavier mineral grain is just large enough to fill the interstices in the quartz. All the minerals heavier than arsenopyrite jig easily; all those that are lighter jig poorly when mixed sizes are used.

The turning point referred to in Figure 7, where the heavy grain is of a size which just fills the interstices among the lighter grains, is represented by the interstitial factor 3.7 of Table XXXVII. This factor has been arrived at in three places in this investigation, namely, by jigging tests Nos 7 and 10, jigging tests Nos. 25 and 28, and the facts brought out in Tables XLVI, XLVII, and XLVIII. The factor will probably vary somewhat with the fracture of the minerals, and it also needs confirmation for larger sizes.

TABLE XLVII.

PERCENTAGE OF HEAVY MINERAL IN TAILS, IN TEST WITH JIG INUNDATED. LITTLE SUCTION.

SIEVE-MESH.	Copper.	Galena.	Antimony.	Arsenopyrite.	Chalocite.	Magnetite.	Pyrrhotite.	Sphalerite.	Epidote.	Quartz in Anthracite.
12	0	0	0	0	0	0	0	0	1	0
14	0	0	0	0	0	2	0	1	3	0
16	0	0	0	0	0	0	0.5	1	8	0
18	0	0	0	1	1	3	1	2	8	0.3
20	0	0	0	1	2	4	2	2	20	0
24	0	0	0.1	1	3	5	4	4	25	0.5
30	2	0.5	0.5	3	4	7	10	6	50	0.5
40	3	1.5	4	6	10	10	15	10	55	1
50	3	3	5	8	15	15	20	15	70	2
60	2	5	10	15	20	20	25	20	75	5
80	5	7	20	25	25	20	35	30	80	50
100	5	10	30	40	40	25	50	50	75	95
120	7	10	40	60	60	40	75	70	80	90
140	7	10	40	75	75	75	95	80	80	80
Slimes	60	80	85	90	95	90	99	90	90	90

While it is a simple matter to make a table of *equal-settling factors* (Table VII), of *interstitial factors* (Table XXXVII) and of *acceleration factors* (Table XXXIX), no corresponding table of *suction factors* can be made. The most that can be said is that suction increases with the length of the plunger stroke, with the difference in specific gravity of the two minerals, and with the diminishing of the thickness of the bed on the sieve, whether of the heavier minerals only or of both minerals.

Summary. — The two chief reactions of jigging are pulsion and suction.

The effect of pulsion depends upon the laws of equal-settling particles, interstitial currents, and, possibly, also of acceleration. The

TABLE XLVIII.

PERCENTAGE OF HEAVY MINERAL IN TAILS, IN TESTS FROM POINTED TUBE OR PULSION-JIG. NO SUCTION.

SIEVE-MESH.	Copper.	Galena.	Antimony.	Arsenopyrite.	Chalcocite.	Magnetite.	Pyrrhotite.	Sphalerite.	Epidote.	Quartz in Anthracite.
12	0	0	0	2	5	0.5	10	25	10	0
14	0	0	0	5	15	5	25	25	25	0
16	0	0	0	10	20	15	30	30	30	1
18	0	0	0	15	30	30	35	40	50	2
20	0	0	0	15	40	40	40	60	50	2
24	0.5	0	0.5	30	40	40	40	60	50	5
30	5	0.5	5	40	50	50	50	60	50	10
40	15	1	30	60	60	50	50	60	60	20
50	20	15	50	60	70	50	60	60	60	20
60	30	30	60	75	70	40	60	60	60	50
80	60	60	70	75	70	40	60	60	60	60
100	65	65	70	75	70	40	60	60	60	60
120	70	70	70	75	70	30	75	60	60	60
140	70	70	75	75	70	30	75	60	60	60
Slimes	70	70	75	75	75	30	75	70	70	40

chief function of pulsion is to save the larger grains of the heavier mineral, or the grains which settle faster and farther than the waste.

The effect of suction depends upon the interstitial factor of the minerals to be separated (see Table XXXVII and Figure 7). If this factor is greater than 3.70, suction will be efficient and rapid. If the factor is less than 3.70, suction will be much hampered and hindered. The use of a long stroke will help to overcome this difficulty. The chief function of suction is to save the particles that are too small to be saved by the laws of equal-settling particles and of interstitial currents acting through the pulsion of the jig.

For jigging mixed sizes, pulsion with full suction should be used.

For jigging closely sized products, pulsion with a minimum of suction should be used.

The degree of sizing needed as preparation for jigging, if we are looking for the most perfect work, depends solely upon the interstitial factor of the minerals to be separated. If the factor is above 3.70 (assuming this value to be sufficiently proved), then sizing is simply a matter of convenience. The fine slimes should, of course, be removed; and if it is more convenient to send egg size, nut size, pea size, and sand size each to its own jig, the suitable screens should be provided for this purpose, and a hydraulic separator for grading the finest sizes. But if, on the other hand, the factor is below 3.70, then the jigging of mixed sizes cannot give perfectly clean work and the separation will be approximate only. To effect the most perfect separation close sizing must be adopted, and the closer the sizes are to each other the more rapid and perfect will the jigging be. There may be conditions where the jigging of mixed sizes of this class will be considered sufficiently satisfactory as an expedient under the circumstances. Indeed, it is probable that as much as 90 per cent. of the mineral was saved in every test recorded in Table XLVI, except that of epidote.

The small scale on which this work has been done may have exaggerated to some extent some of the jigging results. It is hoped, however, that if the reader does not find here the large-scale work exactly pictured, he will find analogies from which he may be able to predict results.

The author is indebted to his assistant, Mr. W. A. Tucker, for the careful and accurate way in which the whole investigation has been conducted; and particularly to Mr. J. B. Seager, graduate of the Michigan Mining School, for the help he has given, not only in conducting the experiments, but also in the way of suggestion and intelligent criticism.

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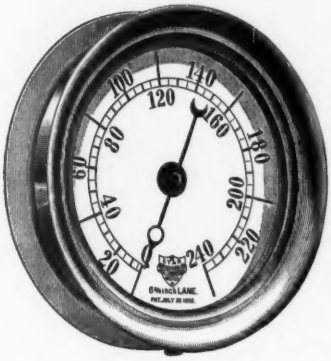

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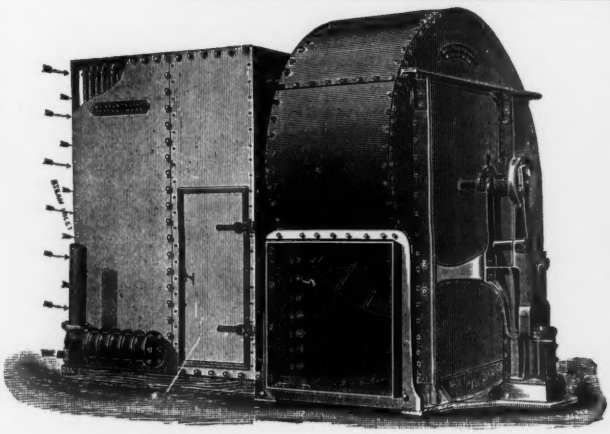

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